ference Proceedings No. 2 Sludge Handling and Disposal

Sludge Handling and Disposal Seminar

Conference Proceedings No. 2

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Research Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

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FOREWORD

The Government of Canada and the Government of the Province of Ontario on August 13, 1971 signed an agreement to ensure that the water quality of the Great lakes is restored and protected. One of the principal provisions was to provide for the acceleration of the construction of municipal sewage treatment projects for the abatement of pollution and to introduce phosphorus removal at all significant municipal sources. An additional important financial provision of the Agreement was for a research program directed towards reducing the cost of waste treatment and ensuring that the latest technological advances were incorporated to achieve the specific water quality objectives set out in the Agreement. A significant concern which was identified was the handling and disposal of sludges produced from the chemical treatment of sewage for phosphorus removal. A subcommittee on the Land Disposal of Sludges was therefore appointed to de develop a strategy for research activities in this area. Under the Canada-Ontario Agreement a number of research projects have been funded, both in-house and by external contracts, to investigate sludge handling and disposal methods.

The disposal of sewage sludge onto agricultural lands under the proper conditions is not only economical but can result in fertilization and improvement of soil properties. Recently, however, questions have arisen concerning the potential environmental problems associated with this method of disposal and the introduction of chemical sludges from phosphorus removal facilities has further complicated these questions. Studies were needed to fully understand and determine the nitrogen balance, and movement and fate of nitrogen compounds in soils, plants and water. The level of heavy metals in sludges is also of concern because of potential problems associated with build-up in soil, uptake by plants, effect on plant growth, runoff, pollution of groundwater and leaching after long-term build-up in soil. In addition, very little is known about the pathogenic aspects of sewage sludge disposal on land.

When the agenda was arranged for this Sludge Handling and Disposal Seminar, an attempt was made to divide the presentation into two areas, namely handling, and disposal with concurrent sessions on the second day. This division was realistic in view of the fact that approximately one-half the sewage sludge from Ontario Water Pollution Control Plants is added to land and one-half is disposed by other means.

The sludge handling topics discussed at the seminar covered such subjects as: dewatering, filtration, centrifugation, incineration, metal removal or reclamation, trucking and pumping. Results of research projects funded under the Canada-Ontario Agreement on both sludge handling and disposal were discussed by approximately thirty authors and researchers. The audience was broad in interest scope consisting of sewage plant operators, administrators, sanitary engineers, pollution oriented researchers and consultants. Regulatory and agricultural personnel from the federal and provincial governments as well as university staff also attended the seminar.

The papers presented and contained herein should serve as a useful reference in the area of sewage sludge handling and disposal.

AVANT-PROPOS

Le 13 août 1971, le gouvernement du Canada et celui de l'Ontario ont signé une entente pour assurer le relèvement et la protection de la qualité des eaux des Grands lacs. L'une des principales dispositions prévoyait d'accélérer la construction d'usines municipales de traitement des eaux d'égout pour réduire la pollution et permettre l'élimination du phosphore provenant de municipalités importantes. De plus, une importante disposition financière de l'entente prévoyait un programme de recherche visant à réduire le coût du traitement des déchets et d'assurer que les récents progrès technologiques soient incorporés au programme afin d'atteindre les objectifs de qualité des eaux fixés dans l'entente. On se préoccupe beaucoup du traitement et de l'élimination des boues produites par le traitement chimique des eaux d'égout pour en éliminer le phosphore. Par conséquent, un sous-comité sur l'élimination des boues dans le sol a été mis sur pied pour élaborer une stratégie de recherche dans ce domaine. Dans le cadre de l'Accord Canada-Ontario, un certain nombre de projets de recherche internes et à contrat ont été subventionnés pour étudier les méthodes de traitement et d'élimination des boues.

L'élimination des boues des eaux d'égout dans les terres agricoles réalisée sous de bonnes conditions est non seulement une solution économique, mais peut permettre la fertilisation du sol et l'amélioration de ses propriété. Toutefois, des questions ont été récemment soulevées concernant les problèmes environnementaux possibles reliés à cette méthode d'élimination, et de plus le problème causé par les boues chimiques qui proviennent des installations d'élimination du phosphore complique la question davantage. Des études étaient nécessaires pour comprendre à fond et déterminer la repartition d'azote ainsi que le mouvement et les réactions des composés azotés dans les sols, les plantes et l'eau. On se préoccupe aussi de la quantité de métaux lourds dans les boues ce qui pourrait causer des problèmes reliés à leur accumulation dans le sol, leur absorption par les plantes, leurs effets sur la croissance des plantes, l'écoulement, la pollution des eaux souterraines et le lessivage du sol après une accumulation à long terme. De plus, on ne connaît presque rien sur les aspects pathogènes de l'élimination des boues des eaux d'égout dans le sol.

Lorsque l'ordre du jour de ce séminaire sur le traitement et l'élimination des boues a été établi, on a tenté de diviser la présentation en deux: le traitement et l'élimination, avec sessions prévues pour le deuxième jour. Cette division était réaliste compte tenu du fait qu'environ la moitié des boues des eaux d'égout provenant d'usines ontariennes de dépollution est éliminée dans le sol et que l'autre moitié l'est par d'autres moyens.

Voici les sujets qui ont été traités au cours du séminaire relativement au traitement des boues: déshydratation, filtration, centrifugation, incinération, élimination ou récupération des métaux, transport par camion et pompage. Les résultats des projets de recherche subventionnés dans le cadre de l'Accord Canada-Ontario et portant sur le traitement et

l'élimination des boues ont été étudiés par environ trente auteurs et chercheurs. L'auditoire était composé d'operateurs d'usine de traitement, d'administrateurs, d'ingénieurs sanitaires ainsi que de chercheurs et conseillers en matière de pollution. Le personnel agricole et les agents de réglementation des autorités fédérales et du gouvernement provincial ainsi que des représentants de certaines universités ont aussi assisté au séminaire.

Les documents présentés (ci-inclus) devraient être utiles dans les domaines du traitement et de l'élimination des boues des eaux d'égout.

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OVERVIEW OF CANADIAN SLUDGE HANDLING AND LAND DISPOSAL PRACTICES AND RESEARCH

by

S.A. Black, Ontario Ministry of the Environment

N.W. Schmidtke, Environment Canada

INTRODUCTION

Sewage sludge is a by-product of sewage treatment processes and the operational phase involving its treatment and disposal is considered to be the most costly phase of sewage treatment. There are a number of alternatives which exist for this operation, but Canadian practice has generally resulted in the selection of the most inexpensive method often with little consideration given to the environmental impact of the ultimate method of disposal. Generally speaking, the most widely practised procedure involves anaerobic digestion followed by dumping into sanitary landfills, sludge storage lagoons or disposal onto farmers' fields.

Keeping in step with the overall concept of recycle, re-use and reclamation, Ontario is now recommending, wherever feasible, the utilization of digested sewage sludge on agricultural lands. Subsequent papers during this seminar will deal specifically with work going on in Ontario and elsewhere directed towards exploiting the full potential of sewage sludge through re-use.

This paper briefly outlines the sludge handling and disposal practises of some of our major Canadian cities and summarizes sludge disposal practices being carried out in Ontario. Areas such as quantities and distribution of sludge production, current sludge treatment and disposal practices and the impact of Ontario's phosphorus removal program on sludge disposal are considered. Current Canadian technology development in the area of sludge handling and disposal will be identified.

SLUDGE HANDLING AND DISPOSAL

Vancouver

Three major waste treatment plants serve the city of Vancouver. At the Lions' Gate plant, primary sludge is treated in a single-stage anaerobic digestion system having a 30 day detention period. Digested sludge at approximately 3% solids is disposed of by discharge into the salt chuck at a rate of 200 gpm for 2 hrs during favorable tide conditions and as sludge accumulation warrants.

Sludge from the Richmond plant at 3% solids is subjected to centrifugation, increasing the solids content to 25%. With a calorific value of approximately 8000 BTU/lb, the sludge is burned in a fluidized bed whereupon the ash is disposed of in a landfill. Current costs are $75 per ton of dry solids but are expected to decrease to $23 per ton once the incinerator capacity is reached.

At the Iona Island treatment plant, primary digested sludge from a two-stage system, having 10 days dentention time per stage, is discharged to four 10-foot deep lagoons during a year round operation. While the influent sludge solids concentration approximates 3%, after lagooning of sludge solids, concentration has increased to 22%.

Edmonton

Waste activated sludge is discharged to heated, single-stage, 20-30 day detention anaerobic digesters. A daily volume of 15,000 gallons of sludge with 3-5% solids requires further disposal. A lagoon system comprised of three lagoons having a total surface area of 40 acres is used for storage and concentration of the sludge. A seven mile, 8 inch diameter pipeline is used for sludge transport from the treatment plant to the lagoon site. One of the three lagoons is used for winter operation, the other two for summer. While the long term phase consists of utilizing the sludge from the lagoons in landfill operations as a cover and soil conditioner, the present mode of operations is as follows. During the winter the sludge is pumped into the winter cell with supernatant draw-off and return to the treatment plant carried out from that cell during the summer. In the summer,

sludge is pumped into the two summer cells with continuous supernatant draw-off and return to the treatment plant.

Calgary

In the more moderate climate of Calgary, approximately 30 tons of 3% solids from the heated, single-stage, 40-50 day retention time anaerobic digester of the Bonnybrook activated sludge plant requires daily disposal. Five miles of 10 inch diameter pipe transport the sludge to lagoons for storage. Two large 15 ft deep winter cells and six smaller 15 ft deep summer cells comprise the sludge disposal system. While the design calls for ultimate abandonment of the lagoons, approximately eight years of lagoon capacity still remains. The supernatant is not returned to the treatment plant, but used to irrigate an adjacent sod farm. The Alberta Department of the Environment is conducting a study concerning the influence of the supernatant on the soil/sod system.

Winnipeg

The city of Winnipeg has been practising a novel method of sludge handling and disposal for years.

The approximately 60 tons per day of 5% solids sludge produced from the North End activated sludge plant after two-stage, high rate, gas mixed digestion are transported from a storage tank via a three mile long, 12-inch diameter pipeline to a lagoon system. Supernatant from the lagoons is returned to the treatment plant during a fill-draw operation of the sludge storage tank.

The total lagoon area made up of 15 lagoons is 88 acres. The method of sludge handling and disposal is as follows. The lagoons are filled to the 4 ft level and allowed to freeze to the bottom. The frozen sludge is ripped up with a cat mounted ripper, scooped up with front end loaders, transported to and spread with graders on nearby fields. The farmer cultivates the land in the spring and crops the same year. Grain crops, such as barley, wheat and oats may be grown. While there is no governmental restriction on the crop use, the growth of forage crops is not encouraged.

The cost of sludge removal consisting of ripping, scooping, transport and spreading has increased from $3.55 per cu yd of dry solids in 1972-73 to $8.00 for 1974-75.

The new South End pure oxygen plant now nearing completion, will thicken its sludge using centrifugation. Present plans call for trucking the sludge to the North End plant for the next five years.

The city of Winnipeg is presently studying ultimate sludge disposal alternatives. While initial considerations centered around incineration as the best alternative for ultimate sludge disposal, the shift in the energy spectrum has again focused attention to anaerobic digestion with associated gas production and utilization at the treatment plant.

Halifax

Halifax, with only 10% of its total generated sewage receiving treatment, has one activated sludge plant in operation. This is a conventional activated sludge plant, but because of underloading is operated as an extended aeration system. Since going on stream 1 1/2 years ago, sludge has only been wasted once and the sludge was hauled 30 miles and spread on agricultural land. The sludge digestion design calls for a two-stage, heated system. For ultimate disposal, landfill is being considered as an alternative but no final decision has been made as yet.

SLUDGE PRODUCTION IN ONTARIO

With a population of some 7.7 million people (1971 census), Ontario has a total of 360 sewage treatment plants 230 of which are mechanical, primary and secondary plants, the remainder being lagoons. Of the mechanical plants, 71% provide for secondary treatment.

The largest plant in Ontario has a design capacity of 180 MIGD, only 6% of the plants have a capacity greater than 10 MIGD and 71% have a design capacity of 2.0 MIGD or less. If one assumes that sludge production from sewage treatment is equivalent to 0.5% of the flow, there are approximately 4.3 million gallons of sludge ranging from 2 to 9% solids produced per day in Ontario which must be

suitably disposed of. The cities of Toronto, Hamilton, London and Ottawa account for about 50% of that sludge. The remaining mechanical plants produce a combined total of some 2.15 million gallons of sludge per day. Thus, there are a lot of plants producing relatively small quantities of sludge, and the economics of sludge treatment and ultimate disposal are different from those of larger municipalities.

PRESENT SLUDGE DISPOSAL PRACTICES IN ONTARIO

Present sludge disposal practices in Ontario include incineration, lagooning, dumping into sanitary landfills, disposal onto farmers' fields, as well as drying and stockpiling for home garden usage. Metro Toronto, Hamilton and London each have sludge incinerators and between them incinerate approximately 41% of the sludge produced in Ontario. Of the remainder, about 70% is disposed of onto farmers' fields, 20% into sanitary landfills and 10% by other means.

Because of their relatively small scale, for the major number of sewage treatment plants in Ontario, land application of sludge is perhaps the most satisfactory solution to the sludge disposal problem. This does not necessarily mean that it is a cheap operation. Sludge haulage costs for land application in Ontario range anywhere from $21.00 to $275.00 per ton dry solids with an average cost of approximately $32.00. This may be compared to reported costs of $25 to $90 per ton dry solids for incineration (1), $10 to $50 per ton dry solids for disposal at landfill sites including dewatering (2), and $1 to $5 per ton dry solids for disposal at landfill sites with no dewatering (2).

IMPACT OF ONTARIO'S PHOSPHORUS REMOVAL PROGRAM

As a result of the 1969 International Joint Commission report (3) recommending that phosphorus discharges from all sources in the Lower Great Lakes be reduced to the lowest practical level, the Province of Ontario announced a policy requiring the installation of phosphorus removal facilities at municipal and institutional wastewater plants in both the Lower Great Lakes areas and in inland recreational waters.

Permanent phosphorus removal facilities were to be operational by December 31, 1973 in the most critically affected areas of the Province and must be operational by December 31, 1975 for those facilities discharging to waters deemed to be in a less critical condition. In all other areas of the Province where no problems are found to exist, permanent phosphorus removal facilities must be operational three years after notification.

Under this program, approximately 100 mechanical plants were affected by the 1973 date, and a further 50 will be affected by the 1975 date, leaving 80 for future notification.

As all phosphorus removal facilities in Ontario will employ chemical precipitation processes, considerable concern has been expressed as to the acceptability of the chemical sludges so produced for land utilization.

The use of chemicals in sewage treatment increases the weight of solids produced, generally increases the volume of sludge to be disposed of and alters its composition. The chemicals will precipitate greater quantities of heavy metals and phosphorus, will affect the nitrogen fractions and the sludge becomes more chemical in nature. The metals used for phosphorus precipitation, aluminum, iron and calcium are themselves, however, abundantly found in natural soils and thus should pose no serious problem. Because of the added chemical, the unit weight of heavy metals and phosphorus per unit of sludge remains approximately the same. Thus, it is felt that when considering their effects on agricultural soils, normal and chemical sludges may be treated alike, except for possible effects on nitrogen availability and sludge decomposition rates.

CANADA/ONTARIO AGREEMENT RESEARCH

Under the Canada-Ontario Agreement (4) joint funding has been provided by the governments of Canada and Ontario for the upgrading of sewage treatment facilities in the Lower Great Lakes Basin. A total of $6 million has been provided over a five year period to conduct related research studies.

Sewage sludge disposal onto agricultural lands has been

practised in Ontario for many years without the identification of any specific problems. The ultimate disposal of sludge was generally of no concern to the sewage treatment plant operator and no particular effort was placed on evaluating this method of disposal. The potential hazards and environmental limitations associated with its usage were never truly considered.

In the environmentally conscious society of today, such a practice is no longer acceptable. Land application of sewage sludge for its soil amendment and fertilizing properties can only be a viable process if the potential hazards and limitations of its usage are clearly defined. Sludge disposal was therefore given a high research priority and a total of ten projects involving agricultural utilization of sludges are being or have been funded under the Canada-Ontario Agreement. These projects may be divided into the five main areas of investigation as listed in Table 1.

Research requirements were also identified in the area of sludge treatment to evaluate and optimize existing processes as they relate to chemical sewage sludges. A total of eleven projects involving the handling and treatment of sewage sludges are being supported by the Canada-Ontario Agreement. These projects may be divided into the four main areas listed in Table 2.

Out of these studies, it is anticipated that a satisfactory system of sludge handling, treatment and disposal may be selected for each facility, and that where land application of sludge is to be practiced, optimum utilization of that sludge may be made without adversely affecting soil, crop, ground or surface waters.

TABLE 1

Research Projects - C-O Agreement

Land Application of Sewage Sludges

1 - Characterization of Sewage Sludges

2 - Laboratory and Greenhouse Studies

3 - Field Trial Studies

4 - Lysimeter Studies

5 - Application Equipment Studies

TABLE 2

Research Projects - C-O Agreement

Handling and Treatment of Sewage Sludges

1 - Sludge Dewatering and Conditioning

2 - Sludge Digestion Studies

3 - Heat Treatment Studies

4 - Reclamation Studies

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(4) Canada-Ontario Agreement on the Lower Great Lakes, August, 1971.

SLUDGE HANDLING AND DISPOSAL PRACTICES IN ENGLAND

by

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In England and Wales where it was estimated in 1970 (Ministry of Housing and Local Government, 1970) that 94% of the population is provided with main drainage, the sewage from rather more than four-fifths of the population, perhaps 43 million, is treated at sewage works. The remainder, mainly from coastal towns, is discharged into estuaries or the sea usually after some minimum pre-treatment.

Of the total sewage sludge produced, estimated to contain 1.1 million metric tons dry solids, about one-fifth is dumped at sea. Two-fifths is applied to agricultural land and the remainder disposed of on land in other ways.

TYPES OF SLUDGE

The aim of sewage treatment is to produce a final effluent which meets the standards proposed by the Royal Commission on Sewage Disposal (1898-1915) of no more than 30 mg/l of suspended solids and 20 mg/l of BOD. This is now thought to be a minimum requirement, especially as the 8:1 dilution with clean water envisaged by the Royal Commission is not always possible today.

Different types of sludge are produced at various points in the treatment works and in any discussion of sewage sludge disposal it is necessary to be clear as to the terminology used. The first stage in sewage treatment after removal of large debris, which may be disintegrated and returned, and grit, is the primary sedimentation of the settleable solids. The sludge removed at this stage, which may contain 60-80% of the settleable solids present is termed "raw sewage sludge".

The settled sewage goes on for biological treatment in which the remaining organic matter is either oxidised or converted into harmless substances by bacteria and other organisms present in the sewage

itself. The 2 main processes are biological filtration in which the sewage is distributed over beds of graded gravel or clinker to which free access of air is allowed and the activated sludge process in which the liquid is aerated either mechanically or by blowing in air. In both cases treatment is followed by further sedimentation to give either humus sludge or activated sludge. These sludges are often mixed with the primary sludge to give "raw mixed sludge".

At the larger sewage works it is normal to further treat the raw sludges by anaerobic digestion and about half the raw sludge produced is so treated. The advantages of this treatment are that the offensive smell of the raw sludge is destroyed, most of the grease in the original sludge is converted to gas and pathogenic organisms are greatly reduced in number. Anaerobic digestion is usually done at 30-35^{o}C in heated tanks. There is appreciable loss, about 50% of organic matter from the sludge, while the nutrients, nitrogen and phosphorus remain. Sludge from the digestion tanks may be disposed of direct as "liquid digested sludge".

Sewage sludge as produced contains 3-4.5% dry matter and where it is to be handled as solids de-watering is carried out. In the past and still at some small works this was done on drying beds where water is lost by evaporation, a process which may take only a few weeks in summer, but up to 6 months or more in winter. This method has the disadvantage of requiring large areas of land (0.5 sq metres per person served in the common estimate) while it also depends on the weather. De-watering reduces the offensive nature of the raw sludge, especially as it is followed up by fairly prolonged storage before use.

Mechanical methods of de-watering are now superseding drying beds at many works. Several methods including pressure filtration, the oldest method, vacuum filtration, belt filtration and the use of plug concentrators. In all cases, the liquid removed is returned to the treatment works. De-watering is greatly helped by the addition of chemicals. The most commonly used are lime with ferrous sulphate (at 25% and 12% of dry solids respectively), hydrated aluminium chloride (aluminium chlorohydrate) and polyelectrolytes. The latter, although expensive, only need to be added at low concentrations (less than 1%

of dry solids) and are tending to replace the older inorganic materials.

DISPOSAL METHODS

To sea. A few large authorities, notably London and Manchester which are suitably situated, dispose of sewage sludge by dumping at sea. The liquid sludge is taken out to sea in specially designed barges or ships for discharge in deep water. It is claimed that no serious pollution occurs although a study of Liverpool Bay, where Manchester discharges its sludge did suggest that an accumulation of some metals, pesticides and other chemicals might occur and be harmful to marine life in the long run.

An alternative way of discharging sewage sludge to sea is by under-water pipeline. Such a method would be very costly to install and has not so far been used in England and Wales.

To land. Disposal to land in some way or other accounts for a large proportion of the sludge produced. A traditional method still used in some cases, but getting less because of pressure to use the land, usually valuable because of its proximity to a large centre of population, for other purposes such as housing is by means of a sewage farm. Such a farm normally adjoining the works would be divided into a number of fields separated by earth banks so as to form shallow lagoons into which the sludge could be pumped. When a sufficient depth of sludge has been deposited, it would be allowed to dry out after which the field would be ploughed and brought back into crop production. At any one time, some fields would be receiving sludge, some drying out and the rest under crop production. Such a system used with domestic sludges from which metal toxicity problems would be unlikely to arise, could go on for very many years. Gradually the characteristics of the soil on the farm would change so that in time crops are grown in an organic medium composed almost entirely of the sewage sludge residues.

Some sewage farms where it was proposed to build houses have been carefully investigated, after analysis had shown high levels of certain metals such as lead in the soil, to assess any possible risks to people who might later live on the site. In general risks appear to be very slight, largely because elements like lead which are dange-

rous to human health are not readily taken up by plants through their roots and so rarely occur at dangerous levels in food crops.

As the population has increased and the pressures on land near large centres of population have grown the possibilities of spreading sewage sludge on farmland not owned or farmed by the Local Authority have been increasingly explored. In many cases liquid digested sludge is now transported and spread on farmers' land using tankers owned and operated by the sewage works. Tankers of 5,000 gallons (23 cu metres) are often used for road transport and the operating radius is normally about 10-15 miles (16-24 kilometres) from the works. One large authority transfers the sludge from the road tankers to smaller tractor drawn tankers of 1,000-2,000 gallons (4.5-9 cu metres) capacity which spread the sludge on the land at rates of about 7,000 gallons per acre (80 cu metres per hectare).

De-watered and dried sludges are also spread on farmers' land in a variety of ways. They tend to be used more on arable land where they can be incorporated in the soil by ploughing while liquid sludges are more often applied to grassland for which they are well suited. De-watered sludges can often be spread on farmland satisfactorily with farmyard manure spreading equipment and a common method would be to transport the sludge from the works to the field by truck which would tip it for loading into the "muck" spreader using a fore-end loader. This method gives a good even spread of sludge making incorporation in the soil easy.

Sewage sludge has also been used to a limited extent in reclamation work especially on old colliery waste tips and reclaimed gravel workings. In both cases the material is almost devoid of organic matter and is deficient in nutrients. Sewage sludge applied in de-watered form at very heavy rates can remedy both defects and good establishment and growth of grass has been reported in a number of cases. This technique was used by Goodman in his investigation into methods of reclamation of toxic wastes remaining from industry in the Lower Swansea Valley, South Wales with some success.

In many cases where disposal is the main problem and the area

of available land is small, sewage sludge is used for filling old gravel workings, clay pits and the like. Such use, while it can be described as "disposal to land" has little agricultural significance.

Other methods. Two other techniques for sewage sludge disposal have occasionally been used, incineration and composting. For contaminated sludges which cannot be used on the land and in situations unsuited for marine disposal incineration is used as a way of very considerably reducing the amount of material to be tipped. Sludges need to be de-watered before being burned and then in many cases they can be incinerated without the use of extra fuel.

The composting of sewage sludge with town refuse has been tried with some success in a few places. Several processes have been used, but all work on similar principles. In the Dano process the mixture of town refuse from which large debris, metals and some other inorganic material has been removed, and the sewage sludge is allowed to pass down a gently inclined slowly rotating drum. Composting starts while the mixture passes through the plant but continues during storage in heaps afterwards. The compost which can be used on farmland is not a very rich source of nutrients and farmers have been reluctant to use it so that some of the plants set up have fallen into disuse. The technique appears to have few advantages except as a way of disposing of town refuse.

MANURIAL VALUE

From both analytical data and field experimental work one can conclude that the main value of sewage sludge on farmland is a source of nitrogen and phosphorus. In recent years the phosphorus content has tended to rise with the increased use of detergents containing phosphates in the home. The potassium content of sewage sludge is usually negligible but in some cases the magnesium present could be of value to crops. Where lime has been added to assist the de-watering of the sludge, it may contain calcium carbonate sufficient to meet the total annual need in many situations.

Typical sewage sludge analyses are given in Table 1.

TABLE 1. TYPICAL SEWAGE SLUDGE ANALYSES.

Sludge	% Dry Matter	% Nitrogen	% Phosphate (P_2O_5)	Reference
Raw Sludge	40	0.9	0.5	Bunting 1963
Digested Sludge	53	1.4	1.1	Bunting 1963
Digested Sludge	34	1.4	1.0	Berryman 1970
Liquid Digested Sludge	2.6	0.19	0.15	Claydon et al 1973

A large body of experimental work was done during the period 1942-1949 on de-watered raw and digested sludges and the results have been published by Bunting (1963). A long term experiment at Woburn on a sandy soil low in organic matter continued over the period 1944-1960 and has been reported by Mann and Patterson (1963). Some of the results for the latter experiment are given in Table 2.

TABLE 2. EFFECTS OF FARMYARD MANURE AND SEWAGE SLUDGE ON CROP YIELDS - WOBURN MARKET GARDEN EXPERIMENT (after Mann and Patterson, 1963). Yields in tonnes per hectare, means for crops from 1951-60.

Treatment	Red Beet	Leeks	Spring Cabbage	Potatoes
No organics	20.03	10.62	15.82	16.04
Farmyard Manure	40.95	14.79	20.21	20.16
Sewage Sludge	33.62	13.18	23.95	18.10

No organics - mean of 75 and 112 Kg/ha N with 37 Kg/ha each P_2O_5 and K_2O.

Organic Manure applied at rates equivalent to 50 t/ha annually from 1944 to 1960.

The results, although influenced by the low levels of fertilizer used for comparison and the possible shortage of potassium in the sewage sludge treated plots, show the large improvements in yield that can be obtained from sewage sludge, especially with a nitrogen responsive crop such as spring cabbage. The 50 tonnes per hectare sewage sludge was estimated to supply 750 Kg/hectare nitrogen and 950 Kg/hectare phosphate (P_2O_5) and nitrogen levels in the soil has risen from 0.09% to 0.26% by 1970 after 16 years of sewage sludge application.

TABLE 3. EFFECTS OF NITROGEN AND SEWAGE SLUDGE ON YIELDS OF POTATOES AND CABBAGE FROM A NITROGEN RESPONSIVE SITE (after Bunting, 1963).

Treatment	No Nitrogen	75 Kg/ha Nitrogen	Effect of Nitrogen
	Potatoes, tuber yield, tonnes/hectare (20 experiments)		
No organic	15.67	20.16	+4.49
Sewage Sludge	19.83	20.71	+0.88
Effect of Sludge	+4.16	+0.55	-3.61
	Cabbage - total yield, tonnes/hectare (6 experiments)		
No organic	16.90	20.41	+3.51
Sewage Sludge	20.34	20.31	-0.03
Effect of Sludge	+3.44	-0.10	-3.54

TABLE 4. EFFECTS OF PHOSPHATE AND SEWAGE SLUDGE ON YIELDS OF POTATOES ON PHOSPHATE RESPONSIVE SITES (after Bunting, 1963).

Treatment	Potatoes, tuber yield, tonnes/hectare (14 experiments)		
	No Phosphate	75Kg/ha Phosphate (P_2O_5)	Effect of Phosphate
No organic	16.39	19.76	+1.34
Sewage sludge	19.91	21.54	+0.65
Effect of sludge	+3.51	+1.78	- 1.73

Some of Bunting's results are given in Tables 3 and 4. They show that in general sewage sludge is a useful source of nitrogen and phosphorus for crops. The nitrogen in de-watered sludges is normally largely in organic form so that only part of the total amount present becomes available in the year of application. There are exceptions, however, and sludges from some woollen manufacturing towns in the North of England have been found to contain large amounts of ammonium nitrogen, probably derived from breakdown of nitrogen compounds in the wool fibre which is present in large amounts in the sludge. In a small number of experiments in which Bunting looked specifically at the availability of phosphorus using swedes and potatoes as test crops he found that it varied from 40 to 100% in terms of equivalent Super-phosphate.

More recently Coker (1966) has investigated the manurial value of liquid digested sludges when used on grassland and for barley. Liquid digested sludge differs from de-watered material having a higher nitrogen content in relation to the dry matter and in that much of the nitrogen present is in organic form. Two series of experiments were done on grass. The first, over 4 years, 1949-1952 on 2 sites measured yields from a single cut taken in June, while in the second, applications of sludge and fertilizer and cuts of grass were taken. Some of the results are given in Tables 5 and 6.

TABLE 5. YIELDS OF GRASS DRY MATTER AND APPARENT NITROGEN RECOVERY IN A SINGLE CUT OF GRASS, MEAN OF 4 YEARS 1959-62 (after Coker, 1966).

Treatment	Annual Yield t/ha		apparent nitrogen recovery %	
	Site A	Site B	Site A	Site B
None	2.31	2.02	-	-
Fertilizer 1	3.30	3.04	35.0	35.4
Fertilizer 2	3.57	3.36	31.0	30.8
Sludge 1	3.38	3.10	27.9	36.0
Sludge 2	3.62	3.35	23.1	25.0

Sewage sludge at Site A 36.7 and 69.5 m^3/ha, Site B 34.2 and 62.3 m^3/ha. Fertilizers with equivalent nitrogen and phosphate. Site A nitrogen 71 and 132 Kg/ha, phosphate 85 and 161 Kg/ha. Site B nitrogen 65 and 118 Kg/ha, phosphate 80 and 145 Kg/ha. Fertilizer plots received water at same volume as equivalent sewage sludge plots.

TABLE 6. YIELDS OF DRY GRASS MATTER AND APPARENT NITROGEN RECOVERY OVER PERIOD 1962-3, MULTIPLE CUT OF GRASS (after Coker, 1966).

Treatment	Total Dry Matter - t/ha	Apparent N Recovery %
No Nitrogen	3.15	-
Nitrogen 573 Kg/ha	14.00	46.4
Sewage sludge 242 m^3/ha	14.96	46.1
Nitrogen and sludge	18.05	37.0

Sewage sludge and nitrogen fertilizer applied in 5 equal dressings. Data are means of plots without and with potash at 66 Kg/ha, the amount applied in the sewage sludge.

These experiments and the single trial in 1970 on barley confirmed that liquid digested sludge was from 80-100% effective as a source of nitrogen as inorganic fertilizer. This is what might be expected from the high proportion of inorganic nitrogen present in the sludge.

OTHER BENEFICIAL FACTORS

In the experiments of Bunting some attempt was made to find out whether sewage sludge had other effects on the soil such as the improvement of soil structure, water holding capacity, etc, due to its organic matter content. While there were suggestions in the data that such effects might occur, the evidence was slight and the conclusion was reached that sewage sludge acts mainly as a source of nutrients. Beneficial effects of farmyard manure on soil structure largely come from the presence of straw and the finely divided organic matter in sewage sludge would not be expected to produce the same effects. However, on sandy soils under intensive cropping some advantages would be expected from increasing the organic matter content. In a series of experiments comparing annual dressings of farmyard manure and sewage sludge applied at 3.75 and 7.5 tonnes/hectare ash-free dry matter for vegetable crops, Webber (1961;1962) showed that at 2 centres they gave similar results (except for runner beans at one site) but at the third, sewage sludge was consistently worse due to the use of too little potash in the early stages of the experiment and possibly the presence of toxic metals in the sludge later on. Even here, most of the effects produced were due to the supply of nutrients although improvement to soil physical condition did occur.

METALS

One of the main differences between sewage sludge and other organic manures lies in its content of metals such as zinc and copper which may be present at levels which may be damaging to crops. In advisory work in England and Wales, many examples have been encountered over the years of reduced crop growth from this cause, especially where sludges from industrial towns have been used.

In order to get information on levels of metals in sewage sludges, a survey of the composition of samples from 42 works in England and Wales was done by Berrow and Webber (1972). They confirmed the presence of metals in all the sewage sludges examined by them and obtained median figures and ranges for metal content which are in line with those from other workers in England (Swanwick, personal communication) and in other countries (quoted by Page, 1974). They considered that zinc and copper with median values more than 40 times the normal amount present in soils were the elements most likely to cause trouble in crops, especially as soluble zinc (extracted with 0.5M acetic acid) was over 500 times the level found in soil and soluble copper about 140 times that in soil. In a few sludges nickel could also present a serious hazard to grop growth.

Some of their results are given in Table 7.

TABLE 7. ZINC, COPPER AND NICKEL CONTENTS OF 42 SEWAGE SLUDGES FROM LOCATIONS IN ENGLAND AND WALES AND COMPARISONS WITH SOILS (after Berrow and Webber, 1972).

Elements	Total Content - ppm		Content Soluble in 0.5 M Acetic Acid - ppm	
	Range	Median	Range	Median
Sewage sludges				
Zinc	700-49000	3000	230-11000	1100
Copper	700-4900	800	3-1400	28
Nickel	20-5300	80	7-2400	25
Soils				
Zinc	10-300	80	< 2-30	2
Copper	2-100	20	< 0.05-1.0	0.2
Nickel	5-500	50	0.1 -5.0	1.0

Other metals, notably lead, cadmium and mercury which are very toxic to man and animals are also of considerable interest. Berrow and

Webber (1972) found a median value for lead in sewage sludge dry matter of 700 ppm with an overall range value 100 to 3,000 ppm of which 0.5-10% was soluble in acetic acid. Cadmium levels in 35 of the 42 sludges they examined were below 100 ppm, their limit of detection, and only one sample had over 1,000 ppm.

Workers in other countires quoted by Page (1974) have found median cadmium values of 12 and 6.7 ppm and median mercury values 3 and 5 ppm for samples from the USA and SWeden respectively.

In England and attempt has been made to establish what are safe levels of addition of metals in sewage sludge to soil from the point of view of crop growth. Chumbley, (1971) made the assumption that toxic effects of metals on plants were additive and from a survey of the available data concluded that copper was twice and nickel 8 times as toxic as zinc. On this basis, it was possible to calculate a "Zinc equivalent" for any sludge from which in turn maximum levels of application which would be safe for crop growth could be worked out. The standard suggested by Chumbley that on uncontaminated soils not more than 250 ppm (500 lb per acre or 560 kg per hectare) zinc equivalent should be added over a long period of say 30 to 50 years has been fairly widely accepted although inevitably it has come in for criticism.

In advisory work we have found the following standards useful.

	Soils - ppm			Plants-ppm in Dry Matter	
Element	Extractant	Normal	Toxic	Normal	Toxic
Zinc	0.5 M Acetic Acid	1-50	100-200	20-100	over 200
Copper	0.05 M EDTA	0.5-5.0	50-100	5-15	over 25
Nickel	0.5 M Acetic Acid	1-5	15-25	1-10	over 50

In order to test some of the assumptions made by Chumbley field experiments have been done over a period of years in which the effects on crops of additions of sewage sludge known to be heavily contaminated with metals have been measured. Some preliminary results were quoted by Webber (1972). The results from one of these experiments have now

been examined in more detail. The soil in this case was a gravelly silt loam with some drainage impedence below 50 cm and pH 6.4. Because of the complex situation due to the fact that each of the sludges used contained all 3 metals: zinc, copper and nickel, multiple regression techniques have been used to assess the toxic effects of each element. From the mean results over the period 1969-72 the following Tables 9 and 10 have been deduced.

TABLE 9. METAL ADDITIONS REQUIRED TO PRODUCE YIELD DEPRESSIONS IN RED BEET AND CELERY - Kg per Hectare.

Crop Yield as % of Control	Red Beet			Celery		
	Zinc	Copper	Nickel	Zinc	Copper	Nickel
99	415	640	145	935	2510*	95
90	460	715	170	1100	2680*	110
50	780	1210*	280	2015	(5240)*	215
% Variance Accounted for		66.5			79.7	

* Figures obtained by extrapolation of the straight line regression.

TABLE 10. EXTRACTABLE METAL CONTENTS OF SOIL IN RELATION TO YIELD DEPRESSIONS IN RED BEET AND CELERY - ppm of dry soil.

Crop Yield as % of Control	Red Beet			Celery		
	Zinc	Copper	Nickel	Zinc	Copper	Nickel
99	170	215	22	420	580	20
90	185	235	45	465	645	22
50	285	360	40	755	1050	30
% Variance Accounted for		59.5			85.5	

Zinc and nickel extracted with 0.5 M acetic acid, copper with 0.05 M EDTA at pH 7.0.

From this data it is clear that both crops are very sensitive to additions of nickel and that nickel is much more toxic to them than either zinc or copper. However, copper in this situation proved to be less toxic than zinc, while its effect on the 2 crops was very different with celery showing considerable tolerance while beet yields were seriously reduced. More work is evidently needed both to examine the varying sensitivities of different crops to metal additions and also to find out whether the same metal in different sewage sludges always behaves in the same way. Data on the chemical combination in which metals occur in sewage sludge are important in the latter connection.

A further big programme of field experimental work is projected and will probable commence in 1975 in which the effects of soil factors such as pH, organic matter content and cation exchange capacity and of sludge origin and composition on toxic effects on crops will be examined. Until this and other work is completed it will not be possible to assess very accurately the risks to crop production from metals contained in sewage sludge to be applied to land.

Less work has been done on other metals, The experiments referred to above also looked at chromium but at the levels tested, 125 tonnes per hectare of sludge containing up to 8,800 ppm chromium, no toxic effects to crops were recorded.

For the elements, lead, cadmium and mercury, the risk to animals and man eating the crops is likely to be greater than those to the crop itself although cadimum appears to behave like zinc and may be equally damaging to a crop's growth. Crop composition data is being obtained from the experiments now under way. In a pot experiment, using a sewage sludge with a high mercury level, but unfortunately also a high zinc level so that heavy rates of application could not be tested, the following figures for uptake of lead and mercury by lettuce and potatoes were obtained.

TABLE 11. MERCURY AND LEAD CONTENTS OF CROPS GROWN IN SOIL/SLUDGE MIXTURES IN POTS - ppm dry matter (means of 6 replicates).

Crop	Soil A		Soil B	
	Range	Mean	Range	Mean
Mercury				
Lettuce	0.31-0.60	0.41	0.13-0.19	0.16
Potato Tubers	0.08-0.18	0.11	0.01-0.09	0.05
Lead				
Lettuce	2.0-7.8	3.7	0.6-2.0	1.3
Potato Tubers	1.5-7.8	5.2	1.5-4.7	2.7

Soil pH 6.8-6.9. Mercury determination on fresh samples and results calculated to dry matter.

Soil A 7.6 ppm mercury, 170 ppm lead, Soil B 9.0 ppm mercury, 110 ppm lead.

In this experiment the amounts of both mecury and lead in the plants increased with increasing metal content in the growing medium, but the experiment needs to be repeated under field conditions to judge its relevance to them.

The problem of metals in sewage sludge are evidently complex and there are differences of opinion as to the likely risks both to crops and animals following applications of sewage sludge to the land. While most agricultural scientists would want to prevent any contamination of soils by elements such as nickel and lead which have no known beneficial effects, it is recognized that some means of disposal of sewage sludge must be found. Sewage sludges also contain increasingly valuable nitrogen and phosphorus compounds. The aim must be to reduce the load of metals and other harmful chemicals as much as possible at the factory where they originate, but in the end a compromise must be reached which will avoid contaminating agricultural land to the point where unacceptable risks to crops and animals will occur, but will yet allow disposal of sewage sludge to farmland and the utilization of the valuable nutrients it contains.

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USE OF SEWAGE SLUDGE IN AGRICULTURE WITH ADEQUATE ENVIRONMENTAL SAFEGUARDS*

by

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ABSTRACT

Sewage Sludge can provide nitrogen, phosphorus, potassium, and micronutrients needed by crops. If properly managed, sewage sludge can be used as a fertilizer and organic matter source in agriculture without creating undue hazards to the environment. Metals in sludge are of concern because of possible long-term reduction in soil productivity and possible increases in toxic metals in the food chain. The amount of nitrogen applied in sludge should be that which is used by crops, is lost as NH_4-N, and is denitrified. Under many conditions it is desirable to build engineering structures and use soil management practices that minimize movement of surface waters off the land.

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INTRODUCTION

Methods for handling and disposal of sewage sludge are being evaluated extensively in the United States, and interest in agricultural use is increasing. Sludge processing and disposal account for half of the operational cost of sewage treatment. Requirements for higher degrees of wastewater treatment result in increasing quantities of sewage sludge and the sludges resulting from these increased levels of treatment are more difficult and more expensive to handle than for present requirements.

Most small communities (less than 50,000 population) in the United States have been disposing of sewage sludge for years by land spreading. In larger communities, where land is not available and transportation distances are greater, sewage sludge is often dewatered and then incinerated. Increased costs, limited availability of supplemental fuel, and more stringent air pollution control are making incineration a less desirable sludge disposal alternative. Disposal into landfills requires improved dewatering techniques to achieve the drier solids content required in new regulations. Higher power and chemical requirements are the disadvantages. Agricultural use of sewage sludge is an apparently desirable alternative because is consumes little when compared to dewatering and incineration. Further, the nutrient value of sewage sludge is appealing as a resource conservation measure in our increasingly environmentally concerned culture.

The metropolitan Sewer Board of the Twin Cities, the Agricultural Research Service and the Soil Conservation Service of the U.S. Department of Agriculture, and the Minnesota Agricultural Experiment Station are engaged in a cooperative program to determine safe, efficient, and practical methods for the application of sewage sludge in harmony with agricultural usage while controlling pollution of surface and ground waters. This program includes evaluating crop yields, heavy metal uptake, sludge application practices, and runoff control. Results of experiments are reported here with sludges from four activated sludge process treatment plants with the following characteristics:

Treatment Plant	Sludge Digestion Practice	Community
Anoka	Anaerobic	Small city with metal plating industry
Orono	Aerobic	Suburban residential
Metro	Undigested	Large metropolitan area with mixed industrial
Stillwater	Anaerobic	Small city with little industry

All of the desired technical information is not now available. However, using what is available, and related agronomic, engineering, and sanitary information, the broad outlines of a technology for use of sewage sludge on land can be put together. This manuscript outlines our experiences and thoughts concerning application of this technology to use of sewage sludge on land.

CROP YIELDS

Use of sewage sludge on infertile cropland can increase production markedly. Crop response in most cases is related to: (a) nitrogen and phosphorus-supplying capacity of the sludge; (b) nutrient status of the soil; (c) nutrient requirements of the crop; (d) amount of water supplied; and (e) water needs of the crop.

Responses of corn and potatoes to sewage sludge applied to an unproductive sandy soil in Minnesota are given in Table 1. Corn yields were increased from 727 to 11,600 kg/ha and potatoes from 18,500 to 66,000 kg/ha. Twelve different crops, including many vegetable crops, have been grown on sludge-amended soils in several experiments in Minnesota. Although growth was not measured for all crops, it appeared to increase markedly with sludge additions up to high rates. In no instance was growth depressed. In these studies, mineral potassium fertilizer was added to all treatments to maximize crop yield and nitrogen phosphorus uptake.

Table 1. Corn and potato yield response to applications of sewage sludge on a Hubbard sandy loam near Elk River, Minnesota.

Corn, 1973			Potatoes, 1972	
Sludge Application Rate * (tonne/ha)	Fodder (tonne/ha)	Grain (kg/ha)	Sludge Application Rate** (tonne/ha)	Potato Yield (kg/ha)
0	4.5	727	0	18,500
81	17.0	10,100	112	44,200
159	16.8	10,600	225	53,100
320	16.6	11,600	450	66,600

* Municipal anaerobically digested sludge from Anoka Wastewater Treatment Plant, Anoka, Minnesota; 4.4% solids, 52% O.M., 5.0% N, and 3.6% P.

** Municipal sludge from a drying bed, Stillwater, Minnesota; 24% O.M., 1.3% N, and 1.8% P.

Sewage sludge has been used to reclaim acid coal stripmine spoils (Lejcher and Kunkle, 1973), sand dunes, sanitary landfills covered with various materials, and an alkali-silica sand waste area, (Peterson et al., 1971). In all cases, crop establishment and growth was improved. In addition to supplying nutrients, sewage sludge improved soil physical conditions for germination and growth. Lejcher and Kunkle (1973) also showed that the pH of an acid stripmined area 18 months after application of 135 dry tons of sewage sludge had increased from 2.3 to 6.3.

HEAVY METALS

In the United States, probably the greatest concern regarding use of sewage wastes on land is the heavy metal content. Sewage sludges contain varying amounts of these so called "heavy" or "true" metals such as Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn. They enter the sewage system primarily from industrial effluents. Considerable concern has been expressed (a) regarding toxicities of these metals to plants and to a possible long-term reduction of soil productivity, (b) possible transport of metals into surface and ground waters, (c) levels of uptake of metals by food crops with possible undesirable effects on animal nutrition, and (d) possible increases of metals in the human food chain from plant or animal tissue.

While few documented cases of research or practice are in the literature, Chaney (1974) argues that excessive metal applications in sewage sludge to the soil can have serious detrimental consequences over the long term. But considering the benefits, what level of metal applications is an acceptable risk? Chumbley (1971) proposed that no more than 250 ppm Zn equivalent* (Z.E.) from Zn, Cu, and Ni in sewage sludge over a long period of time to be added to soils (at pH $\geq$ 6.5). Leeper (1972) suggested that individual toxic metals up to 5% of the cation exchange capacity (CEC) could be added over time. Chaney (1974) recommended that metal additions to agricultural soils should not

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* Chumbley defined the zinc equivalent as Zn (eq) = 1 Zn + 2 Cu + 8 Ni

exceed Zn (eq) levels equal to 5% of CEC of unamended soils at pH $\geq$6.5, but suggests that with additional information this limit may likely be set higher.

Chaney (1974) has proposed the following upper limits of metals in sludge for land application: Zn 2000 ppm, Cu 1000 ppm, Ni 200 ppm, Cd 1% of Zn, B 100 ppm, Pb 1000 ppm, Cr 1000 ppm, and Hg 10 ppm. Figure 1 expresses the long time amounts of sludge application as related to the CEC for two sludges using the equation for calculating Zn (eq) and using 5% of the CEC as the upper limit. The line labelled maximum limits represents a sludge having concentrations of 2000 ppm of Zn, 1000 ppm of Cu, and 200 ppm of Ni as proposed by Chaney. The line labelled Stillwater was calculated from analyses of the Stillwater, Minnesota, sludge. Also drawn on Figure 1 are average ranges of CEC for different soil textures as given by Donahue et al. (1971). The maximum long-term amount of sludge (tonne/ha) using average CEC for the different textures and the maximum metal concentrations in tonne per hectare are: sands, 20; fine sandy loams, 155; loams and silt loams, 210; and clay loams, 470.

According to the Stillwater line in Figure 1, the maximum amount of Stillwater sludge that could be applied to a Hubbard coarse sand (Udorthentic Haplorolls) with a CEC of 4.2 is 87 tonne/ha. In an experiment on the Hubbard soil, up to 450 tonne/ha of sludge were applied to the field and the metal uptake by seven vegetable crops was measured (Dowdy and Larson, 1974).

Table 2 presents data for concentration of selected metals by three of the seven crops from a soil amended with sewage sludge during the first year after application. The soil had a pH of 5.3 at the time of sludge application in the spring and a pH of 6.5 in the sludge amended treatments at crop harvest time. Marked crop growth response to sludge application was evident on all treatments receiving sludge.

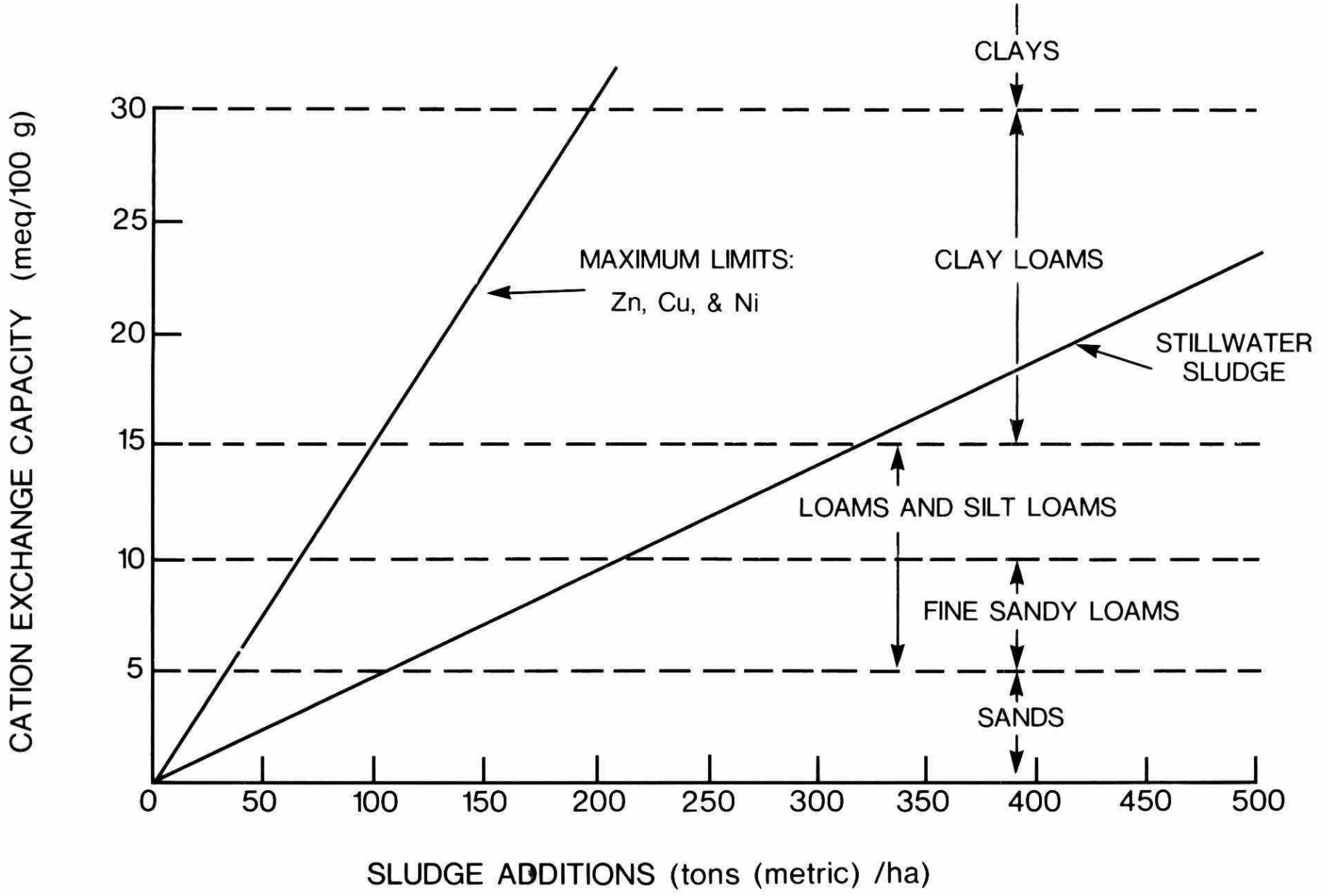

Figure 1. Sewage Sludge Application Rates as a Function of Soil Cation Exchange Capacity Following the Recommendations of Chaney (1974): Maximum Limits Line Represents a Sludge Containing 2000 ppm Zn, 1000 ppm Cu, and 200 ppm Ni; Stillwater Sludge Line Represents a Relatively Clean Material Containing 1070 ppm Zn, 245 ppm Cu, and 24 ppm Ni.

Table 2. Total analyses for selected elements of various plant parts.*

Sludge applied **	ELEMENT Mn	Zn	Cu	Cd	Pb	B
tonne/ha	- - - - - - ppm - - - - - -

Although sludge application significantly increases metal uptake by certain crops, the concentrations are below the suggested tolerance level for plants, and in most cases within the common average composition range for crop growth as suggested by Melsted (1973).

In another experiment, three different sludges were added to Hubbard sand (CEC = 6.7) and metal uptake by corn grain was measured. The Anoka sludge was added to the soil at about 11X the calculated maximum rate (as suggested by Chaney), the Orono at about 1.3X the calculated rate, and the Metro at about 5X the calculated limits (Table 3). Manganese in corn fodder grown in the Anoka and Metro sludge treatments, zinc in the fodder from the Anoka sludge, and cadmium in the fodder from the Metro treatment was greater than the common average composition range (Melsted, 1973).

The data in Table 2 were obtained from a single year experiment and data in Table 3 from the second year in which sludge was applied. Metal concentrations may increase as the organic matter in the sludge-amended soil decreases (Leeper, 1972).

The standard for maximum concentration of Cd (0.015 of Zn or 15 ppm) as proposed by Chaney (1974) may eliminate more sludges from land application than concentration of any other element. Data are inadequate for assessing the amounts of cadmium various plants will absorb or what plant and food levels are dangerous to humans. The sludges used in the experiments reported in Tables 2 and 3 all had about 10 ppm cadmium, except the Metro sludge which had a concentration of 320 ppm and a Zn-Cd ratio of 4:6.

For protection of soil productivity and composition of human foods, the concentration and total amount of metals in sludge for land application must be restricted. Sludges from domestic sources usually have suitable metal concentrations and thus have the greatest potential for agricultural use. Sludges from highly industrialized communities that contain large amounts of metals clearly should not be put on land used for growing agricultural crops. In these communities, prevention of the metals from entering the sewage water should be emphasized.

Table 3. Metal uptake by corn as influenced by source and amount of sludge.*

Sludge Source	Calc. Limit of Sludge	Sludge Applied	Metal Content						
			Mn	Zn	Cu	Cd	Pb	Cr	B
	(tonne/ha)		- - - - - - - - - - -ppm- - - - - - - - - - - - -						
			Grain						
Check	--	0	6	36	1.7	0.04	<0.2	0.1	3.1
Anoka**	30	320	10	64	1.3	0.04	<0.1	0.1	3.8
Orono***	114	145	7	46	0.9	0.04	<0.1	<0.1	3.5
Metro****	54	250	10	54	3.1	0.24	<0.1	0.1	3.7
			Fodder						
Check	--	0	92	47	4.1	0.10	11.0	1.0	8.5
Anoka	30	320	202	164	5.4	0.20	1.8	2.1	7.6
Orono	114	145	70	65	5.7	0.11	2.5	0.8	7.5
Metro	54	250	199	105	8.4	4.49	2.2	1.0	8.8

* Values reported on 70 C weight basis.

** Elemental concentration of the sludge (110 C weight basis) in ppm; Anoka: Mn 477, Zn 2570, Cu 1880, Cd 11, Pb 2630, Cr 1025, B 38.

*** Orono: Mn 835, Zn 1050, Cu 485, Cd 6, Pb 140, Cr 24, B 46.

**** Metor: Mn 358, Zn 1480, Cu 843, Cd 320, Pb 590, Cr 1560, B 28.

Agricultural managers have many options that can be used to keep dangerous concentrations of metals from damaging the soil and keeping the metals out of the food chain. These options include selection of soil type, control of soil pH, crop residue management, selection of crop, and use of the crop.

NITROGEN MANAGEMENT

We believe that, over the short term, transport of nitrate into ground water or surface water is the major potential hazard from use of sewage sludge on land. Thus, only as much N should be applied with sludge as can be used by crops or lost by volatilization.

A nitrogen balance estimate for a cropping system receiving sludge must consider the chemical nature and quantity of nitrogen in the sludge, volatilization losses of ammonia, rate of mineralization of the added organic nitrogen and native organic nitrogen, denitrification losses, and expected quantity of nitrogen that will be removed in the harvested portion of a crop (Miller, 1974).

Miller (1974) found from 3.3 to 13.4% of the sludge organic nitrogen was mineralized nitrogen in the displaced soil solution of a sandy soil after 6 months of incubation. Our field studies suggest that Miller's range of values for mineralization would apply for anaerobically digested sewage sludge during the first year after its incorporation in the soil. Mineralization of organic nitrogen from sewage sludge over a number of years will probably follow a decay series.

In our Minnesota studies, the NH_4-N content of anaerobically digested sewage sludge has averaged about 35% of the total N. King (1973) showed that much of the N is lost as NH_3 when sludge is applied to the soil surface. In laboratory experiments, Ryan and Keeney (1974) found that from 11 to 60% of the NH_4-N was lost by volatilization, depending on characteristics of the soil and amount of NH_4-N added.

No estimates of the denitrification rate in a soil management system utilizing sludge are available, but the rate may be higher than in most soils without sludge because of an abundant energy source

and possibly a lower level of soil oxygen. Allison (1955) observed that the average N loss from 57 lysimeter experiments was 15%. The loss could have been from chemical or biological denitrification. Miller (1974) speculates that under high loading of sewage sludge and effluents, denitrification losses could run as high as 40 to 50% of the mineralized nitrogen. In laboratory experiments when organic N (up to 0.18% by weight) was added to soil, Ryan et al. (1973) found that up to 38% of the nitrogen was not recovered and presumably was denitrified. At low rates of organic nitrogen addition, the complete recovery of nitrogen indicated no denitrification occurred.

Figure 2 is presented to illustrate possible amounts of nitrogen contained in sludge, possible transformations in the forms of nitrogen during the first year after field application, and possible amounts of nitrogen available for crop growth. It is assumed that the sludge contains 5% N on a dry-weight basis, of which 3.33% is in the organic form and 1.67% is NH_4-N. These values are typical for anaerobically digested sludges in plants operated by the Metropolitan Sewer Board in the St.Paul-Minneapolis area. It is further assumed that the liquid sludge is surface applied and 50% of the NH_4-N is volatilized and lost to the atmosphere. In addition, it is assumed that 10% of the organic N is mineralized and 40% of the mineral N is denitrified. Using these assumptions, the amount of available N for different amounts of applied sludge is shown as the solid line in Figure 2.

The estimates in Figure 2 are based on assumptions whose reality cannot be documented with present data. Further, the actual values will vary with kind of sludge, method of application to the land, and soil conditions. However, we believe the values are reasonable estimates for our experiments and we present them to illustrate how one may estimate reasonable field loading rates.

From Figure 2 it is estimated that 20 metric tons of sludge will produce 150 kg of nitrogen available for plant uptake. This amount of nitrogen per hectare is often required for high production of nonleguminous crops in Minnesota and is commonly applied to soil

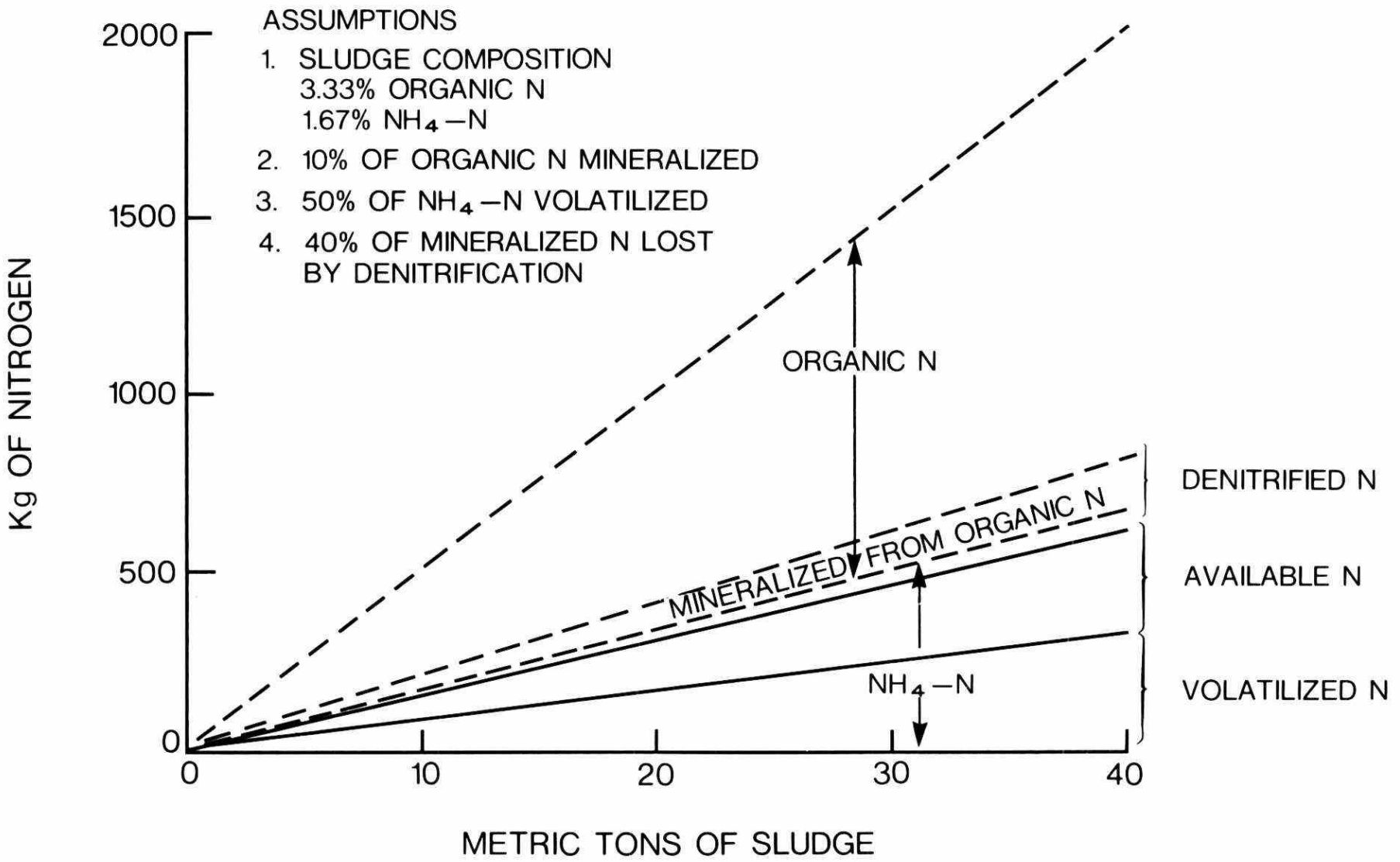

Figure 2. Estimated Amount of Available Nitrogen From Various Amounts of Sewage Sludge (Distance Between Solid Lines Denotes Total Available N).

that is used for corn production. This, it appears to be a reasonable application rate for the first year of application.

MOVEMENT OF CHEMICALS INTO SURFACE AND GROUND WATERS

Materials from sewage sludge can be carried in surface runoff waters and into streams and lakes unless adequate control structures are provided. The amount of movement will depend on soil type, slope length and steepness, intensity of rain, degree of incorporation of the sewage sludge, and soil management. The chemicals moved may be inorganic nutrients derived from the sludge, organic particulates, or chemicals absorbed on the soil.

Figure 3 presents an engineering diagram of a research watershed we are currently studying. The 20-hectare watershed is on the Rosemount Agricultural Experiment Station of the University of Minnesota (SE $\frac{1}{4}$ sec 10, Empire Township, Dakota County) near Rosemount, Minnesota. The soil at the watershed site has from 2 to 8 feet of silt loam overlying compact glacial till. Port Byron, Bold, and Tallula soils are the dominant soil types. Dominant slopes before terracing ranged from 6 to 12%. Level terraces with grassed backslopes and surface-inlet tile drains were built. The terraces are designed to impound a maximum of 6.3 cm of runoff and release it through surface tile inlets. Solid PVC pipe was used to connect the tile inlets to the sampling station as shown in Figure 3. After a runoff event, water from each surface inlet is sampled for analyses. After sampling, the reservoir is emptied by irrigating a separate 2-hectare portion of the watershed cropped to grass (Area C).

The water storage reservoir was built to hold a rainstorm with a probability of 100-year frequency (11.2 cm of runoff). As a precaution, the 10-year frequency water storage pool above the dam was lined with plastic sheets to limit seepage into ground water above the dense glacial till.

Wet, digested sludge (approximately 2 to 6% solids) from four suburban treatment plants is hauled to the site by tank trucks and placed in the storage lagoon. The lagoons are large enough to

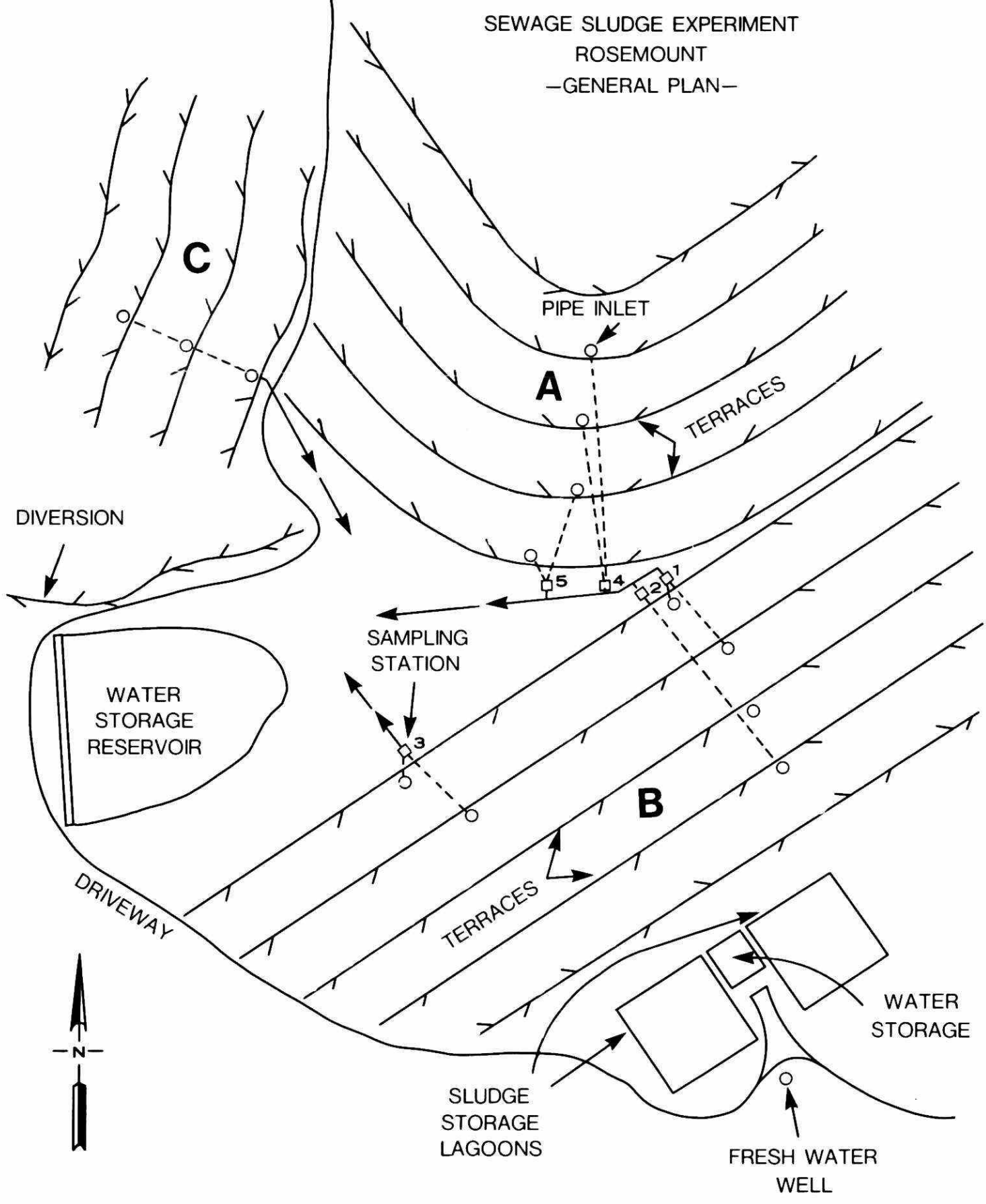

Figure 3. A General Diagram of the Terraced Watershed Near Rosemount, Minnesota, Where Land Application of Sewage Sludge is Being Studied.

provide about 5 months' storage from the four treatment plants (1.5 million gallons each). The lagoon presently used is lined with polyethylene and a standby lagoon is not lined. Measurements in the laboratory and the field show that the sludge will effectively seal the unlined lagoon and prevent measurable seepage. Construction of the water control and sludge storage lagoons was completed in 1973.

Sewage sludge was applied to area A of the watershed during April and May 1974 by surface spreading with a tank wagon. Thus far, the design seems to be adequate for controlling contamination of downstream surface water.

PRACTICAL MANAGEMENT SCHEMES

Any practical scheme for using sewage sludge on agricultural land must include practices for high crop production, practices for controlling surface waters and sediment transport, and mechanical devices for handling the sludge.

High crop production is desirable to offset costs and to remove plant nutrients through harvest, particularly nitrogen. Sludge should be applied at a rate such that nitrate production does not greatly exceed crop uptake and removal, and losses by denitrification and volatilization. Table 4 gives the estimated maximum removal of N at St.Paul, Minnesota, by a few common crops. Corn for silage and reed canarygrass are being grown in our watershed research (Figure 3). The sludge is applied to the areas of corn and grass in the spring and fall and to the grass immediately after each harvest. This permits sludge application during all months when the soil is not frozen.

Tillage with a chisel plow is being compared with conventional tillage (moldboard plow, disk, harrow). We believe the chisel plow tillage will minimize runoff and erosion (Wischmeier, 1973) and thus minimize movement of nutrients and other chemicals off the land. A cover crop of winter annual rye may also be desirable for winter erosion protection and uptake of nutrients in the late fall and spring.

Underground pipe has been laid from the sludge storage lagoons at approximate right angles across the terraces. Alternate

Table 4. Maximum yield and nutrient removal by crops at St.Paul, Minnesota.

Corp	Dry Matter Yield tonne/ha	Nutrient Removal: Nitrogen kg/ha	Nutrient Removal: Phosphorus kg/ha	Nutrient Removal: Potassium kg/ha
Reed canarygrass	13	585	52	260
Alfalfa	13	520	52	325
Corn silage	27	405	54	260
Corn grain	10	200	45	35

terrace channels have an outlet for connecting irrigation equipment. A drain in the line is provided at the low point. A small well provides clean water for flushing the lines after each irrigation with sludge. Currently, we are using a traveling "big gun" with mobile hose for distributing the sludge on the field.

CONCLUSIONS

Sewage sludge can provide nitrogen, phosphorus, and micronutrients needed by crops. If properly handled, sewage sludges can be used on farms. Metals contained in sludge are of concern because of possible long-term reduction in soil productivity and from possible increases in the human food chain. Only as much nitrogen should be applied with sludge as can be used by crops. The necessity for control structures to prevent sewage sludge materials from being carried into surface waters is being evaluated. Practical farm management schemes need to be developed for safe and economical use of sludge on private farms.

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AEROBIC AND ANAEROBIC SLUDGE DIGESTION

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INTRODUCTION

The design of water pollution control plants is primarily concerned with the production of high quality effluents. In achieving this goal through removal of organic pollutants, considerable quantities of sludge are produced that cannot normally be disposed of without some means of pre-treatment. The fundamental aim of digestion is to provide treatment for those solids separated in primary and secondary wastewater treatment processes, thus allowing subsequent disposal.

More specifically, the objectives of digestion are: reduction of volatile organic matter accompanied by stabilization of the remaining organic matter to reduce or eliminate putrescence on disposal, reduction of the volume of sludge to be handled, and reduction of pathogenic organisms. All of these objectives are generally aimed at improving the properties of the raw sludge, e.g. unpleasant smell of raw sludge replaced by a tarry odour, reduction in grease content, more readily dewatered sludge, bacteriologically safer product with respect to land application. Such sludge treatment can be achieved either through anaerobic digestion, i.e. stabilization in the absence of oxygen, or aerobic digestion involving stabilization in the presence of dissolved oxygen.

The oldest form of anaerobic digestion is the cesspool that ultimately evolved into the present-day septic tank. Although providing a dewatering function, septic tank sludges still have a very objectionable odour probably the result of sludge being in contact with putrescent sewage during the digestion process. Anaerobic digestion in one form or another has been used in mechanical plants since the late 19th century with the process being extensively used in the treatment of wastewater solids since the turn of the century. While research work was conducted on aerobic digestion as early as 1933, it was not until the early 1960's that aerobic digestion became commonly used in North America.

ANAEROBIC DIGESTION

Process Description

Anaerobic digestion is a biological-chemical process in which the solid material (sludge) undergoes liquefaction and hydrolysis, decomposition, gasification, and mineralization through the action of microorganisms and enzymes in an environment characterized by the absence of oxygen. This degradation of sewage sludge normally takes place in a heated closed tank equipped with a mixing device and a gas collection system.

While all the above mechanisms are involved in the stabilization of sewage sludges, anaerobic digestion is generally considered to be a concurrent two-phase process consisting of an acid fermentation phase and an alkaline fermentation, or methane, phase.

In the acid fermentation stage, the initial action taking place is liquefaction or the microbial-enzymatic transformation of sludge particles into finely dispersed particulate matter and/or soluble organic compounds. These soluble organic compounds then undergo hydrolysis, i.e. the addition of water to a complex organic molecule thus breaking it down into simpler organic structures. Again, this hydrolysis is effected by microbial enzymes acting as biological catalysts in promoting the breakdown of organics. Thus carbohydrates are hydrolyzed into simple sugars, proteins into amino acids, and fats into glycerol and fatty acids. The final action of acid-producing bacteria in this phase of digestion is to further degrade the simple organic compounds into alcohols, aldehydes, and simple organic acids along with the production of ammonia from degradation of amino acids.

In the alkaline fermentation stage, the simpler fatty acids, aldehydes, and alcohols are converted to methane and carbon dioxide by methane-producing bacteria. Although the mechanism for the production of methane is still a matter of speculation, radioactive tracer experiments have shown that in the case of acetic acid, the methane is formed from the methyl (CH_3) group, and the carbon dioxide by the decarboxylation of the acid (COOH) group. Mineralization of the conversion of organically bound elements into inorganic salts may be considered to take place throughout

the entire digestion process.

Thus there are two phases proceeding concurrently during anaerobic digestion; if the digestion is proceeding satisfactorily and the acid fermentation is not allowed to dominate, the mixture should remain very slightly alkaline.

Figure 1 illustrates the fate of typical complex organic compounds undergoing anaerobic digestion.

Typical Facilities

The design components of present anaerobic digestion units are the closed digestion tank, gas collection system, method of circulation and recirculation of sludge, and sludge heating system. Present anaerobic digestion systems are either single- or two-stage units, both types of which have the common features outlined above.

In the traditional single-stage digester limited mixing, confined to the upper volume of the digester, is usually provided through sludge recirculation. The lower portion of the digester is allowed to remain quiescent to provide sludge concentration. Because of the limited mixing provided by the design, single-stage digester contents stratify, resulting in an upper relatively inactive scum layer, a central supernatant layer, a lower relatively active layer of digester solids and a bottom layer of stabilized sludge. Such single-stage digestion is frequently referred to as "conventional" digestion with "high-rate" digestion referring to two-stage digestion featuring a completely mixed primary digestion tank.

Larger treatment plants usually effect sludge digestion in two physical stages:

(1) Primary digestion is conducted in heated, mixed, closed tanks, provided with fixed or floating roofs, usually for a retention period of 7-20 days at 95^{o}F. Most of the digestion and gas production takes place in this stage. Heating is usually carried out by circulating the tank contents through an external heat exchanger using part of the gas evolved during digestion as a source of heat. Mixing is provided either through gas recirculation or mechanical mixing. Because the tank is highly mixed, a supernatant liquor is not obtained and relatively homogeneous tank contents are transferred to the secondary digester, or second stage.

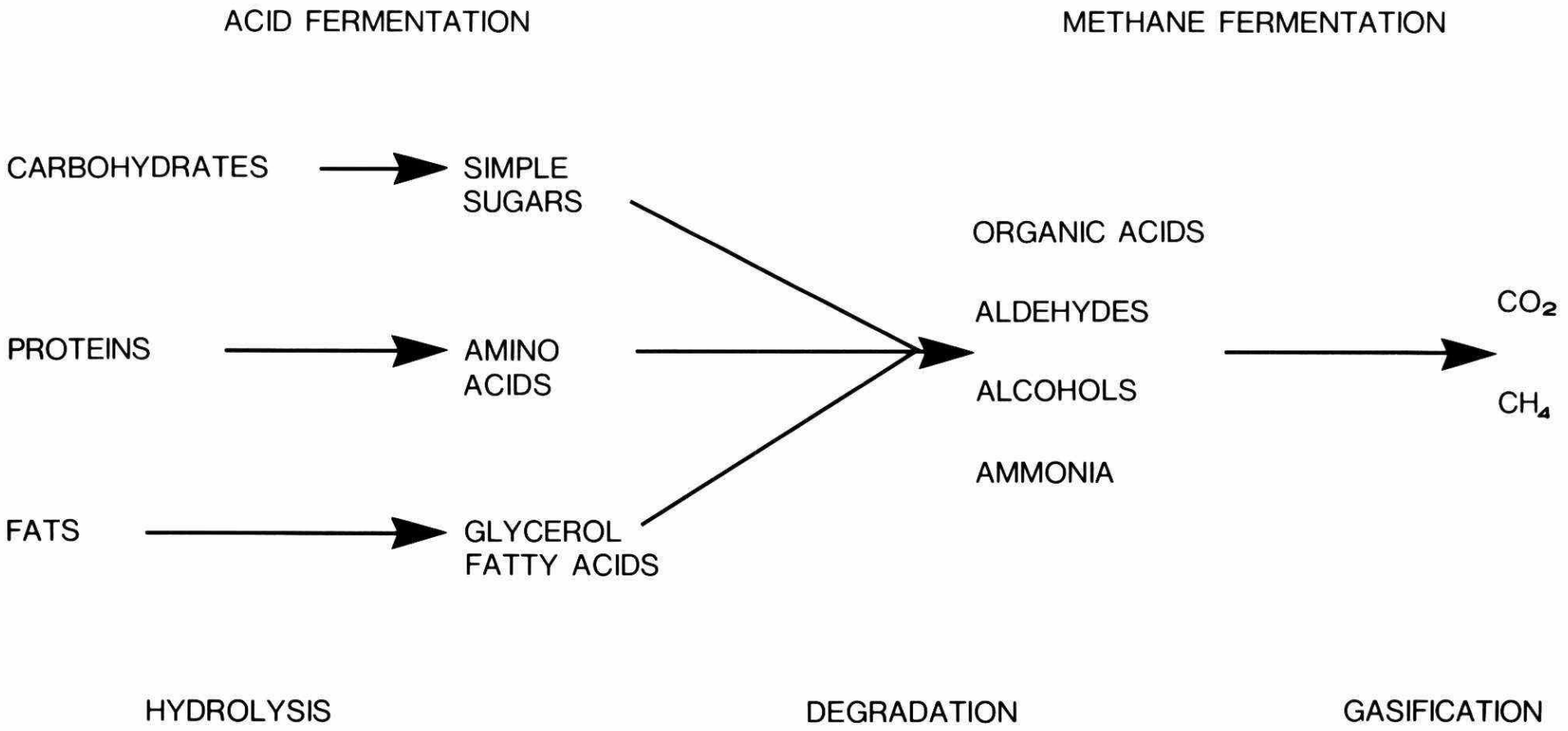

Fig. 1: Anaerobic Digestion Process

(2) Secondary stage digestion is then provided, again in closed tanks, for further digestion and for some solids concentration with removal of supernatant liquor. Although the secondary stage is left unheated, provision is made for gas collection.

Figure 2 is a schematic drawing of a typical two-stage anaerobic digestion system.

Factors Affecting Anaerobic Digestion

A major factor affecting anaerobic digestion performance is the loading rate usually expressed as pounds of volatile solids added per cubic foot of digester tank capacity per day (lb vs/cu ft/day). This loading term is analagous to the volumetric loading parameter frequently used in design of activated sludge systems. With two-stage digestion systems, present loadings range from 0.10 to 0.25 lb vs/cu ft/day, based on only the first mixed stage of the digestion system. Corresponding detention times for the higher loading levels are approximately 10 days, assuming a sludge having 5 percent total solids concentration and containing 70 percent volatile matter in the solids. For optimum operation, the daily organic loading to the digester should be spread out over a 24 hours period rather than being applied in one or two massive slug feedings. Excessive daily organic loadings to anaerobic digesters or massive slug feedings will both result in an upset of the digestion process and the excess production of digestion intermediates such as volatile acids. High volatile acid concentrations should be considered an effect rather than a cause of digester upset. This excessive acid fermentation rate results in a depressing of the pH of the digester contents thus inhibiting alkaline methane fermentation. If such a condition is allowed to continue, process failure ultimately results with a complete cessation of gas production.

As temperature has a marked effect on microbial metabolism, anaerobic digestion systems are operated at an elevated temperature, usually 95°F, in order to increase the rate of digestion. Although numerous studies have indicated that the digestion process can be satisfactorily effected in either the mesophilic (approximately 90-95°F) range or the thermophilic (125-135°F) range, virtually all anaerobic

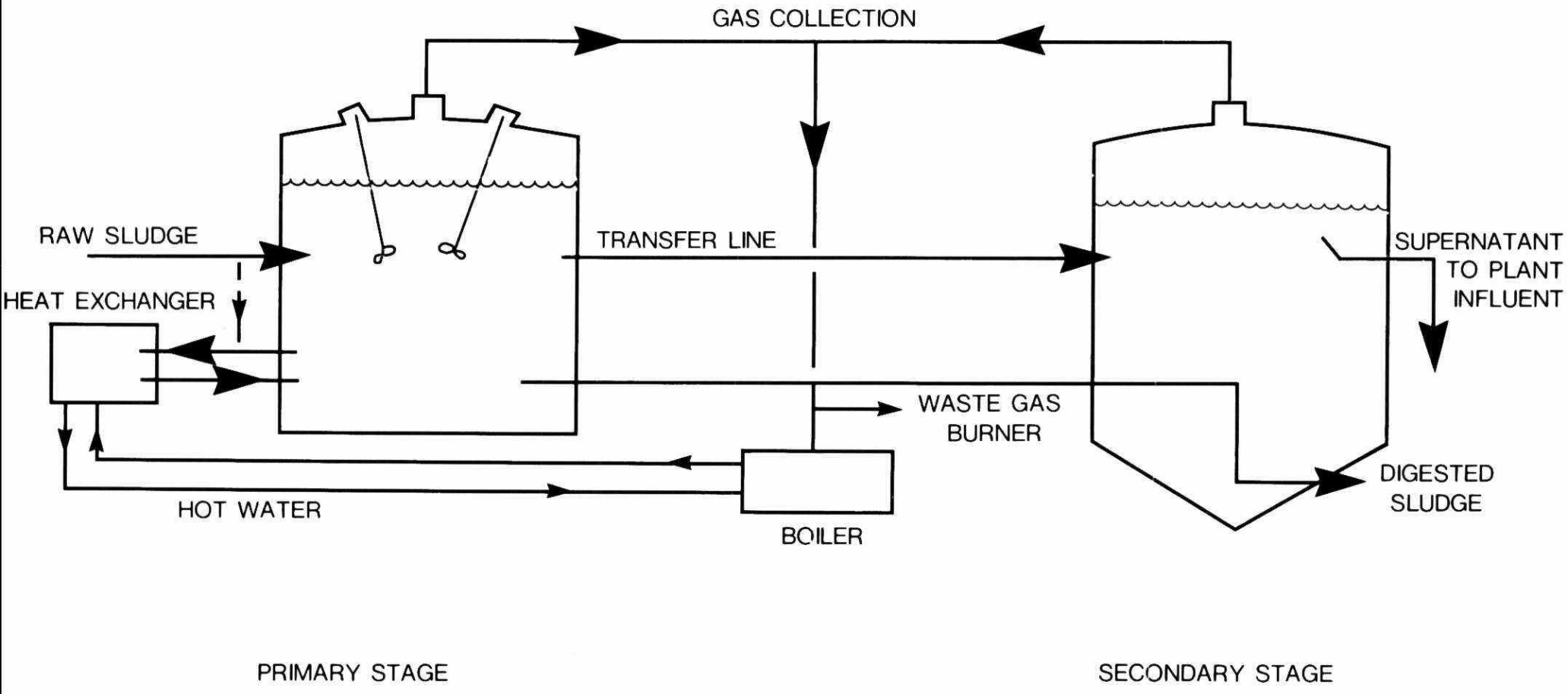

Fig. 2: Two-Stage Anaerobic Digestion System

digestion systems are designed for operation at 95°F. Limited data on full scale thermophilic performance coupled with the lack of an economic evaluation of thermophilic operation has resulted in a continuing use of mesophilic digestion. Heating of digestion tank contents is normally done through the use of external heat exchangers rather than internal hot water piping. Some research work has been conducted using submerged combustion and subsurface steam injection although these heating methods have been primarily used to satisfy heating requirements for particular research needs rather than as an investigation into alternative sludge heating methods. Because of the ease of maintenance, external heat exchangers are almost excusively used for sludge heating at present.

Efficient mixing of digesting sludge is require to ensure:

(1) intimate mixing of raw sludge with active sludge mass,
(2) thermal homogeneity and minimum stratification,
(3) elimination of dead spots or 'cold storage' of organic matter and a reduction of scum blanket.

It was initially thought that recirculation of digesting sludge through external heat exchangers would provide adequate mixing within the digester; presently the two methods that provide adequate digester mixing are gas mixing featuring continuous digester gas recirculation or internal mechanical mixers. Both of these systems should maintain a 'mixed liquor' condition in all parts of the digestion tank and the addition of new mateial results in the displacement of 'mixed liquor' rather than supernatant liquor or sludge.

Frequently single-stage digestion units are provided with mixers designed to run during raw sludge additions in order to disperse the raw sludge within the actively digesting mass. In addition, this intermittent mixing is also aimed at providing adequate scum blanket control.

In addition to control of the external variables affecting the anaerobic digestion process, a suibable chemical environment within the digester must also be maintained. Chemical parameters that are normally monitored to indicate both the stage of the digestion process and indication of potential inhibition are pH, volatile acids, alkalinity, ammonia, and qualitative analysis of digester gas. In addition,

the daily quantity of digester gas produced is also used as an indication of digester performance. Although routinely monitored, toxic wastes such as heavy metals can adversely affect the rate of digestion. The pH, volatile acids, and alkalinity are inter-related with respect to digestion performance and numerous theories on the interaction of these parameters have been put forth. While it is universally agreed that the volatile acids concentration must be controlled in order to avert digester upset, one school of thought is that the volatile acids themselves are responsible for reducing methane production while other commonly held view is that volatile acids are toxic indirectly through a reduction in pH. Other research studies have indicated that the salts of the volatile acids which are formed after neutralization of high volatile acids concentrations are toxic to the methane producing organisms. In these cases the sodium and potassium cations are considered to be responsible for the acute toxicity to methane bacteria, while calcium salts are not considered toxic to these organisms. Although the explanations for digester upsets during periods of high volatile acids concentrations are varied, it is generally agreed that lime is an excellent neutralizing agent for restoring alkaline conditions within the anaerobic digestion process. Again, it should be kept in mind that high volatile acids concentrations and low digester pH are the results of digestion upset rather than the cause of such upsets.

Ammonia can be toxic if present in high enough concentrations; however, at normal digestion pH's such concentrations are rarely obtained.

Although numerous references are made to toxic metals reducing the activity of the anaerobic digestion process, this toxicity is only achieved when the metal, etc., is in a soluble form or is converted to a soluble form and absorbed in the cell structure. The inhibitor effect of toxic materials is further complicated by the possibility of acclimatization to metallic ions if buildup of concentration is gradual. Care must therefore be taken before the failure of a digestion process can be attributed to toxic metals. Too frequently industrial discharges are automatically considered as the cause of various process failure within a treatment facility. Where toxic heavy metals are know to interfere with the anaerobic digestion

process, the addition of sulphide to the system precipitates such interferring constituents and thus renders them non-toxic. It is likely that this action of precipitating heavy metals through sulphide complexing takes place routinely within an anaerobic digestion system due to the reduction of organic sulphur present in the raw sludge. Similarly, the reaction of generated sulphide with heavy metals present in sludge likely accounts for the relative absence of hydrogen sulphide in digester gases.

Performance

The anaerobic digestion process normally attains a 40 - 50 percent reduction in total volatile solids content of the raw sludge. Although some volume reduction of sludge quantity is expected, a review of Ministry of the Environment operating records indicates that no generalization can be made in this area. Obtaining large quantities of digester supernatant would appear to be ideal but care must be taken to ensure that such supernatant does not exert an appreciable loading on the secondary treatment section and that an excessive solids recycle system is not established.

Gas production in the order of 15 - 20 cu ft/lb of volatile solids destroyed can be expected during normal digestion with the gas containing 65 - 75 percent methane and 25 - 30 percent carbon dioxide. Although trace quantities of hydrogen, carbon monoxide, nitrogen, oxygen, and hydrogen sulphide have been found in digester gases, the total concentration of these other constituents rarely exceeds 5 percent by volume and is usually neglected. Since sludge gas is used almost exclusively for fuel, and its calorific value is directly proportional to the methane content, it is advantageous to have as great a methane content as possible. The calorific value of sludge gas is normally about 700 - 750 BTU/cu ft.

With the implementation of the phosphorus removal programme in Ontario, the volatile content in raw sludges is expected to decrease somewhat due to the inorganic salts being used for phosphorus removal. With the use of lime the volatile content of raw sewage would drop drastically. It should be pointed out that when calculating digester efficiencies in the normal manner (based on mass balance of ash content

in sludge), low efficiency figures may be obtained if the volatile solids content in the raw sludge is very low. In spite of such apparently low efficiencies, adequate digestion may be taking place and a review of gas production and gas quality should be made before assuming digestion inhibition has taken place.

Studies conducted to date on the digestion of chemical - organic sludges containing high quantities of precipitated phosphorus have indicated that no release of phosphorus takes place under the anaerobic conditions encountered in a digester. Ortho phosphorus concentrations in such digested sludges and supernatants are generally below 20 mg/l P.

AEROBIC DIGESTION

Process Description

Aerobic digestion may be defined as an aerobic biological process featuring a long solids retention time and can be described as an extension of the extended aeration process. The gross oxidation in the system includes the direct oxidation of any bio-degradable matter by microorganisms and the oxidation of microbial cellular material through endogenous respiration. Catabolism, or auto-digestion of cell protoplasm, takes place only when there is insufficient organic material for microbial synthesis and energy generation. During aerobic digestion, the biologically degradable organic matter in the sludge is oxidized to carbon dioxide and water, with the production of ammonia which in turn is subsequently oxidized to nitrate. The sludge residue then consists of fixed solids and non-degradable volatile solids. As is the case with anaerobic digestion, aerobic stabilization of sludge is not carried out to complete mineralization but only to a certain degree of stabilization. At present, there is no firm definition of the degree of stabilization required by aerobic digestion. Aerobic digestion does not result in the production of any form of usable energy and, on the contrary, the oxygen demand of aerobically digesting sludge requires additional energy in the form of aeration.

Figure 3 illustrates the aerobic digestion process.

Typical Facilities

Aerobic digestion commonly takes place in a separate unheated aeration tank equipped with either a mechanical or diffused air aeration system. Tank configurations may be either circular, rectangular, or annular segments with liquid depth ranging from 10 - 15 feet SWD. Single and two-stage aerobic digestion systems are common with both having provision for decanting digester supernatant. Although attempts have been made to design an internal stilling well within the digester itself, the use of stilling wells has largely been abandoned because of excessive turbulence resulting in high concentrations of SS in the supernatant.

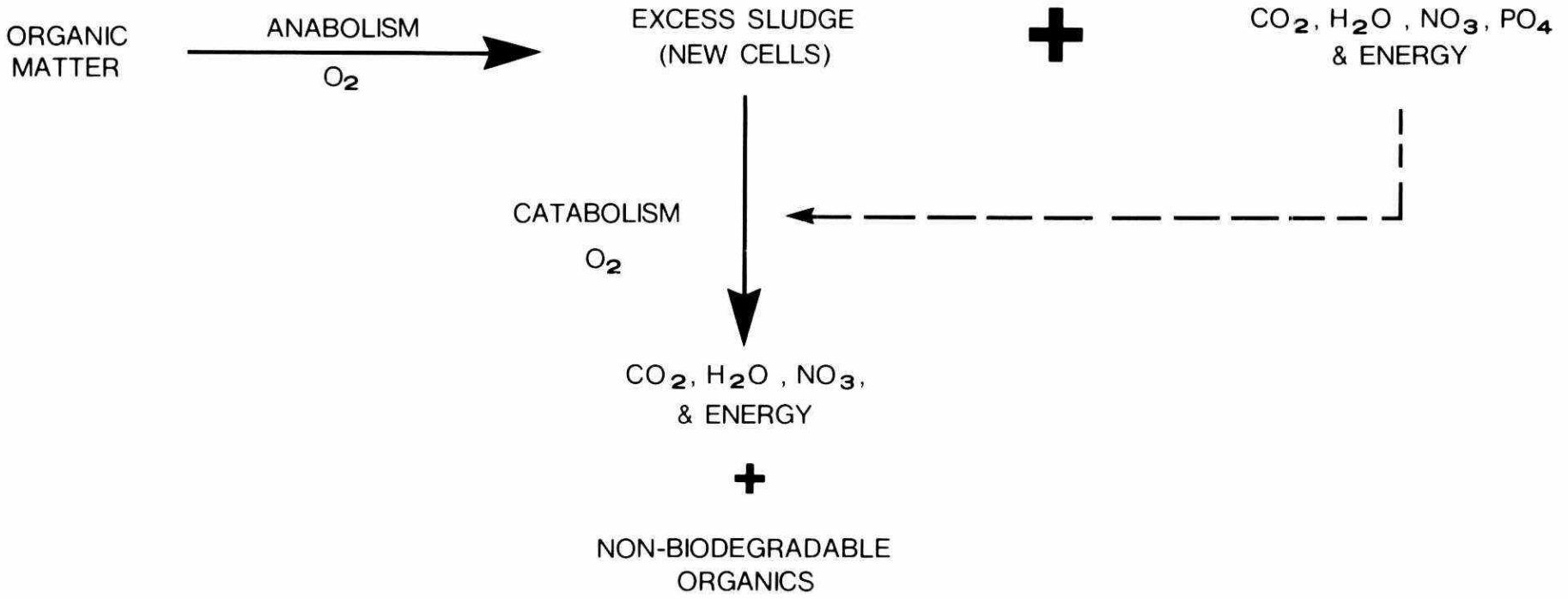

Fig. 3: Aerobic Digestion Process

With the relatively long retention times required for sludge stabilization (sludge ages in excess of 45 days), excessive heat loss at low temperatures can result in ice formation thus causing operational problems. Heat losses can be minimized through the use of common wall construction or earth embankments around isolated tanks.

Factors Affecting Aerobic Digestion

The major factor affecting the aerobic digestion process is the ability of the aeration system to maintain an oxidizing environment as characterized by satisfactory dissolved oxygen levels and oxidation-reduction potentials. Volumetric organic loading, expressed in terms of lb vs/cu ft/day, is not particularly significant for these systems. Although inter-related, sludge age rather than volumetric organic loading is the major parameter that determines the degree of stabilization that can be realized.

Although temperature directly affects the rate of metabolic activity of microorganisms, the principal effects of temperatures extremes in aerobic digesters have been foaming at high temperatures and icing at low temperatures. Because of the relatively long retention times required for sludge stabilization in an aerobic digester, the reduced biological activity at lower temperatures does not significantly affect the performance of the aerobic digestion system. In order to reduce the icing problems commonly occurring in digesters operating at $0^{o}C$, heat losses from the aerobic digester should be kept to a minimum. This can be accomplished bydesigning the aerobic digester to share common walls with the main processing tanks or providing an earth embankment around an isolated tank. In addition, long air supply headers can be insulated to further reduce heat losses. The physical design becomes especially important if mechanical aerators are considered because one potential heat source available with diffused air systems is lost.

As with the activated sludge process, complete mixing is required in the aerobic digestion system to ensure uniform distribution of feed sludge through the digester and to maintain an adequate dissolved oxygen concentration in all portions of the tank. In order to prevent a

loss of digester capacity due to solids deposition, aeration devices should be capable of maintaining a 6 percent solids concentration in suspension and resuspending this concentration following the long settling period required for obtaining supernatant. Solids deposition may result from a number of factors including the method of operating the digester, tank configuration, location of air diffusers, solids concentration in the digester, and type of sludge fed to the digester.

Aerobic digestion is subject to the same inhibitory effects of toxic materials as is the anaerobic digestion process. However, as toxicity is primarily caused by ions rather than by insoluble materials, care again should be taken when considering industrial discharges as a potential cause of aerobic digestion upset. While the concentration of metals in solution is usually low in aerobic digesters, high metal concentrations in digested sludges from plants receiving industrial discharges have been observed and these could pose a long-term problem if the sludge were ultimately disposed on agricultural land.

Performance

In contrast to anaerobic digestion the performance of an aerobic digester is best gauged by determination of the specific oxygen utilization rate in the digesting sludge rather than vs reduction. This rate is normally expressed in terms of mg O_2/g vss/hour and well stabilized sludges will have specific uptake rates in the range of 0.5 - 1.0 mg O_2/g vss/hour. While a percent volatile solids reduction can be calculated for an aerobic digestion system, the performance of the system cannot be universally judged on the basis of percent vs reduction alone because of different raw waste characteristics. The same percent reduction of volatile solids should not be expected with waste activated sludge from an extended aeration plant as that achieved in digesting primary sludge because of the gross difference in initial sludge ages. The volatile fraction in waste sludges with a high initial sludge age is generally resultant from accumulation of biologically inert volatile matter thus not allowing a high degree of vs reduction.

In most cases, the process state of the digester can be established by the DO level, the oxidation-reduction potential, and the

nitrate concentration. If all of these values are high, (DO greater than 1 mg/l, ORP greater than 400 mvE_h, and nitrate nitrogen greater than 10 mg/l), the process is normally performing satisfactorily.

Field studies conducted by the Research Branch of the Ministry of the Environment have indicated that, with coarse bubble devices, air rates of 50 - 60 cfm/1000 cu ft of digester capacity should be provided to ensure satisfactory residual DO's and adequate mixing.

Apart from the stability and concentration of digesting sludge, the next most important aspect of aerobic digestion is the production of a low strength supernatant to minimize any additional load on the activated sludge process. A high solids concentration in the supernatant does not necessarily indicate a high organic load to the aeration tanks, with such organic loading being represented by the supernatant soluble BOD, usually less than 100 mg/l.

COMPARISON OF ANAEROBIC AND AEROBIC DIGESTION SYSTEMS

While a direct comparison can be made between the anaerobic and aerobic digestion processes, citing advantages and disadvantages of each system, these two methods of sludge stabilization should not be considered as equal alternatives when considering a sludge treatment facility. Each system has particular features and requirements that usually allow a clear choice to be made betweeen the two methods of sludge stabilization.

Because of the high air requirements when handling primary sludges, aerobic digestion is most suitable in plants having to stabilize waste activated sludges only. Such plants are usually smaller facilities and the simplicity of aerobic digestion process operation also favours installation of such systems at small WPCP's. Other advantages of aerobic digestion systems which become more pronounced when considering small treatment facilities are:

(1) supplementary heating not usually required for digester,
(2) waste sludges of low solids concentration may be handled on a batch basis,
(3) good quality supernatant minimizing any effect on activated sludge system, and
(4) minimal supervision for process control.

The anaerobic digestion process is most suitable for handling raw and mixed primary sludges which have appreciably higher oxygenation requirements than those of waste activated sludges. With the anaerobic digestion system, higher organic loadings may be used to achieve a reduction in gross tank volume required for sludge stabilization (0.1 - 0.2 lb vs/cu ft/day with an anaerobic digestion system compared with 0.05 lb vs/cu ft/day with aerobic digestion). A large treatment facility is more likely to make use of the usable end product of anaerobic digestion, methane. Total energy requirements for the anaerobic digestion process when using digester gas as a boiler fuel are quite low compared to the cost of aeration for aerobic digestion systems.

When considering process failures in both the aerobic and anaerobic digestion systems, it must be recognized that the recovery procedure for an aerobic digestion system is considerable less complex

than that for an anaerobic system. In most cases aerobic digestion upsets are resolved by ensuring the presence of an adequate dissolved oxygen concentration in the digester, usually through reducing the organic load either present or applied. With the anaerobic digestion system, restoration of the process is a somewhat long procedure, involving constant monitoring of chemical parameters indicating restoration of the anaerobic microbial system.

BIOCHEMICAL CHARACTERISTICS OF DIGESTED CHEMICAL SEWAGE SLUDGES

by

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1 INTRODUCTION

Many sewage treatment plants in Ontario are incorporating phosphorus removal systems in existing facilities by the addition of alum, ferric chloride or lime as a precipitating agent. Phosphorus rich chemical sewage sludges from these plants with their different chemical compositions have raised many new environmental questions with respect to land disposal.

Nutrients, metals, organic and microbial constituents could be increased considerably in such sludges and may potentially pollute surface and ground waters, soil and plant systems.

To assess these biochemical characteristics and their variability and entensive study program was initiated in 1973 at the Wastewater Technology Centre, Burlington. Four sewage treatment plants which had implemented removal programs were studied over a period of fifteen months. Basic plant data are tabulated in Table 1.

TABLE 1. SEWAGE TREATMENT PLANTS STUDIED 1973-74.

PLANT	MEAN DAILY FLOW		DIGESTION STAGES	CHEMICAL PRECIPITANT	CHEMICAL DOSAGE TO INFLUENT mg/l
	MIGD	m^3/day			
North Toronto	7.90	35,700	3	$FeCl_3$	7
Point Edward	0.24	1,090	1	Alum and $FeCl_3$ + Lime	250 25 + 120
Newmarket	1.6	7,270	2	Lime	200
Sarnia	7.0	31,800	1	$FeCl_3$	10

2 MATERIAL AND METHODS

2.1 Sampling

Digested sludge samples were collected each week in four-liter containers from North Toronto, Newmarket, Point Edward and Sarnia sewage treatment plants. These weekly grab samples were manually obtained by treatment plant personnel from a suitable location in digester drawoff pipes.

2.2 Analysis

Nutrient analyses were performed according to Standard Methods (1971) utilizing auto-analyzer techniques. Ammonia-N determinations were made on the filtrates. Total Kjeldahl nitrogen-N, total phosphorous-P, and total carbon determinations were made on the unfiltered fractions. Total heavy metals were determined by atomic absorption techniques. Microbiological, pesticide and lipid analyses were done on homogenized unfiltered samples. Gas chromatographic and infrared spectrophotometric techniques were used for the analyses of lipids and petroleum hydrocarbons. Procedures used for pesticide analysis were the same as given by Chau (1972).

3 NUTRIENTS AND HEAVY METALS

3.1 Nutrients

Overall mean concentrations were calculated for each sludge over the entire sampling period of January 1973 to March 1974. Monthly mean levels of nutrients were analyzed to assess the long range temporal variability and the average composition of sludges produced.

Linear regressions of TKN, total phosphorous and total carbon were performed on one another to determine the degree of correlation which could be expected among these parameters in the digested sludges.

Estimations have been made of the number of samples required for each parameter at each treatment plant to obtain estimates of population means within ±10% of the true value at a 95% confidence level using standard statistical methods (Cochran, 1963).

Overall mean nutrient concentrations, standard deviations, and 95% confidence limits are expressed in Table 2. Results obtained from the

TABLE 2. MEAN CONCENTRATIONS (mg/1) OF NUTRIENTS IN DIGESTED SLUDGES - 1973-74

SLUDGE SOURCE	NORTH TORONTO			POINT EDWARD			NEWMARKET			SARNIA		
SLUDGE TYPE	FERRIC CHLORIDE			ALUM			LIME			FERRIC CHLORIDE		
	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL
TKN-N	2510	860	235	1300	610	155	1150	520	138	2310	870	278
NH_3-N	744	110	29	290	100	25	292	126	33	416	132	42
TP-P	1420	710	190	1310	466	118	665	393	104	1250	840	267
TOTAL SOLIDS %	6.25	0.90	0.24	6.90	3.70	0.94	12.2	5.92	1.54	16.19	3.93	1.27

estimation of the number of samples required to predict population means with the given precision of ±10% are tabulated in Table 3.

3.1.1 Nitrogen

Monthly mean total Kjeldhl nitrogen-N and ammonia-N concentrations are plotted in Figures 1 and 2 respectively. It is apparent from Figure 1 that similar overall increases in TKN-N concentrations were observed in each sludge during the study period. Minimum mean monthly TKN-N concentrations occurred during April, 1973 (Figure 1). However, evidence of a cyclic trend in TKN-N concentration was not decisively confirmed in this study. Highest overall mean TKN-N concentrations were observed at the North Toronto plant followed closely by the Sarnia plant, with the lowest concentrations occurring at the Newmarket plant (Table 2). Overall mean concentrations of TKN-N ranged from 1150 mg/l at North Toronto. These values are in agreement with other studies reported by Coker (1971), Menzies (1973) and Sommers et al (1973).

Only the Point Edward sludge demonstrated a significant correlation of TKN-N concentration with total solids. However, a possible reason for this apparent correlation may have been the change from alum to a lime-ferric chloride precipitation process at this plant resulting in a independent increase in total solids.

TKN-N concentrations were positively correlated to the total phosphorous concentrations in each digested sludge at the 99% level. Correlation coefficients are shown in Table 4. TKN-N concentrations were also correlated to the total carbon contents, and coefficients were significant at 99% level at the North Toronto, Point Edward and Sarnia plants (Table 4).

The estimated number of samples required to predict TKN-N population means with a ±10% precision (Table 3) were dependent on the variability within each plant. North Toronto was the most uniform sludge, requiring fewer samples than actually collected in this study to obtain the given precision of ±10%. Other plants would require more analyses than performed in this study for the same precision.

Ammonia-N concentrations deviated randomly from their respective means at each treatment plant. They accounted for an average of 24%

TABLE 3. ESTIMATED NUMBER OF SAMPLES REQUIRED TO PREDICT MEAN CONCENTRATIONS OF NUTRIENTS WITHIN ± 10% OF POPULATION MEANS AT 95% LEVEL

SLUDGE SOURCE	NORTH TORONTO		POINT EDWARD		NEWMARKET		SARNIA	
SLUDGE TYPE	FERRIC CHLORIDE		ALUM		LIME		FERRIC CHLORIDE	
	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS
TKN-N	47	45	88	28	82	182	57	93
NH_3-N	9	13	48	96	74	209	40	58
TP-P	100	94	51	51	140	51	181	172
SAMPLES IN THIS STUDY	56		62		57		40	

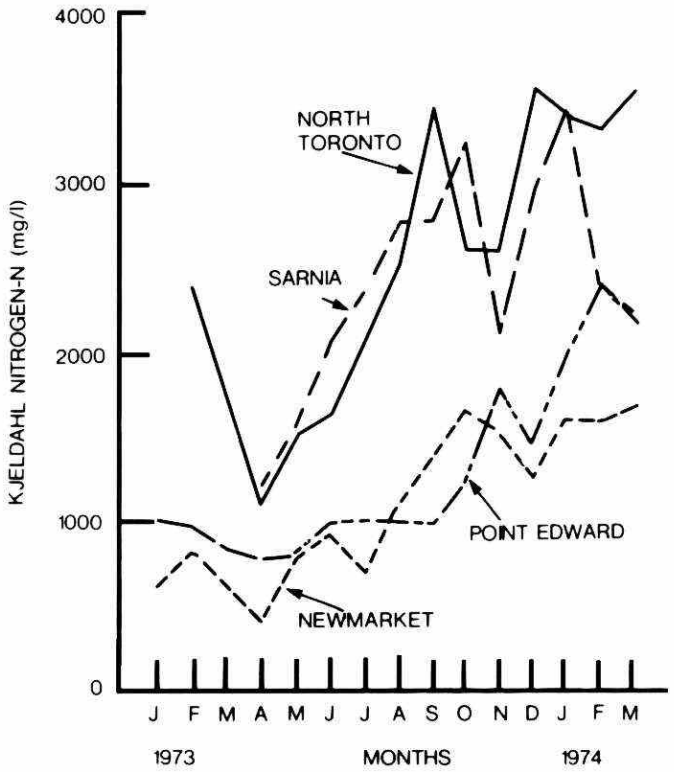

FIG. 1 TOTAL KJELDAHL NITROGEN-N CONCENTRATIONS IN DIGESTED SLUDGES

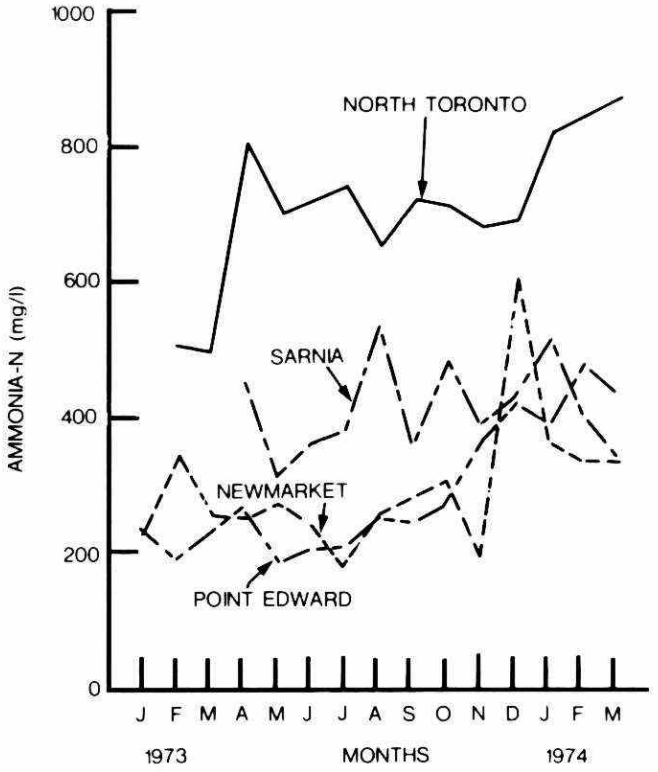

FIG. 2 AMMONIA-N CONCENTRATIONS IN DIGESTED SLUDGES

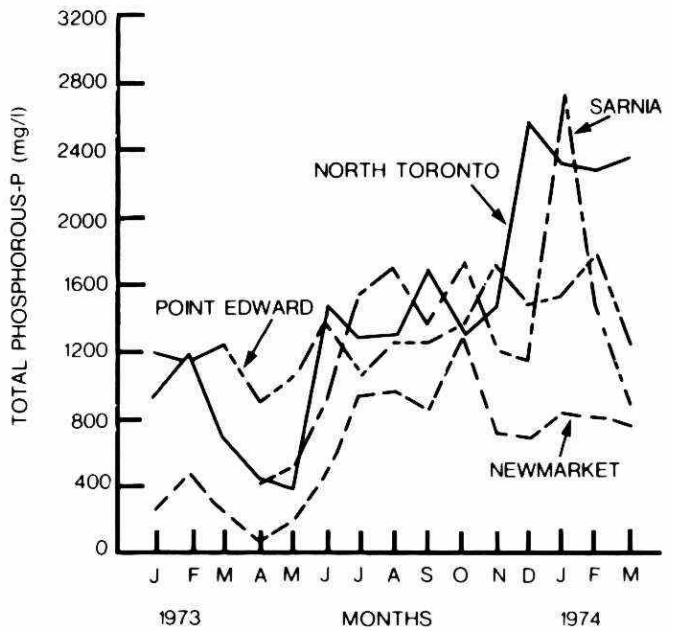

FIG. 3 TOTAL PHOSPHORUS-P CONCENTRATIONS IN DIGESTED SLUDGES

TABLE 4. CORRELATION COEFFICIENTS OF MAJOR NUTRIENTS IN DIGESTED SLUDGES

SLUDGE SOURCE	NORTH TORONTO	POINT EDWARD	NEWMARKET	SARNIA
SLUDGE TYPE	FERRIC CHLORIDE	ALUM	LIME	FERRIC CHLORIDE
	r	r	r	r
TKN.TP	0.811**	0.716**	0.729**	0.877**
TKN.TC	0.584**	0.731**	0.226	0.521**
TP.TC	0.508**	0.626**	0.264	0.421**

* - 95% LEVEL OF CONFIDENCE

** - 99% LEVEL OF CONFIDENCE

of the overall TKN-N concentrations in the four sludges collectively. The North Toronto sludge had the highest NH_3-N fraction at 30% of the overall mean while the Sarnia sludge had the lowest at 18% (Table 5). As NH_3-N concentrations were relatively constant, the increases in TKN-N concentration were related to increases in organic N.

TABLE 5. OVERALL MEAN PERCENT TKN-N AS NH_3N.

SLUDGES	NH_3-N/TKN-N x 100
North Toronto	30%
Point Edward	22%
Newmarket	25%
Sarnia	18%
Mean	24%

3.1.2 Phosphorus

Monthly mean total-P concentrations are plotted in Figure 3 for each sludge. Increasing trends were generally evident in the total-P concentrations. A monthly low concentration was observed during April, 1973 averaging 450 mg/l total-P in the plants collectively, and a monthly high averaging 1840 mg/l was observed in January, 1974. North Toronto digested sludge had the highest overall mean total-P concentration at 1420 mg/l followed closely by the Point Edward sludge at 1310 mg/l. Newmarket sludge had the lowest total-P concentration at 665 mg/l. All concentrations lie within ranges reported by Dean (1973), Coker (1971) and Menzies (1973). North Toronto sludge was much less uniform in total-P content than TKN-N content. It is apparent that considerably more samples are required to predict total-P content with the same precision as TKN-N and NH_3-N content (Table 3).

Regression analyses of total-P concentrations versus corresponding total solids concentration in each sludge indicated a very weak correlation. Point Edward sludge was again an exception due to a change in chemical precipitant rather than to a true correlation. Significant correlations were obtained between total-P and total-C content in three of the four

sludges. As indicated previously, total-P concentrations were correlated to TKN-N concentrations at the 99% level in all four sludges (Table 4).

3.2 Heavy Metals

Overall mean heavy metals concentrations with corresponding standard deviations and ±95% confidence limits are reported in Table 6. Percent total solids are reported also. Results on the dry weight basis are presented in Table 7. Respective numbers of samples required to predict population means within ±10% with a 95% level of confidence were calculated on wet weight and dry weight bases. Results are tabulated in Table 8.

Heavy metals have been reported as invariably tied up with the sludge solids (Abbott, 1971; Sommers *et al*, 1973; Van Loon *et al*, 1973). Heavy metals concentrations were linearly regressed against total solids concentrations; the majority of correlation coefficients were found to be significant.

3.2.1 Nickel, Copper, Zinc

Nickel concentrations in sewage sludges and their toxicity have been reported by many workers (Dean, 1973; Webber, 1972; Sommers *et al*, 1973; Pauly, 1971; Lisk, 1972; Oden, 1970). In relation to sludges from European countries and the U.S.A., it is apparent that overall mean Ni concentrations in these four sludges are low (Tables 6 and 7). Sarnia sludge contained the highest Ni concentrations at 6.3 mg/l (39 mg/kg total solids), but on the dry weight basis the North Toronto sludge had similar concentrations.

Monthly nickel concentrations (Figure 4) depict no clearly evident trends; however, significantly higher concentrations were obtained in the Sarnia sludge during the summer months of 1973 (July and August) followed by a gradual decline. This is possibly the result of inadvertant industrial discharges to the sewer system (Abbott, 1971). Monthly variations appear to be random in nature at the remaining plants.

Correlation coefficients of nickel versus total solids contents were of low magnitude suggesting a weak relationship between these two parameters. Low nickel concentrations affected the prediction of ±95% confidence limits (Table 6), and the estimated number of samples of ±10% precision on the Ni population means (Table 8). However, nickel concentrations are sufficiently low to permit a prediction of probable maximum concentrations with relative confidence.

TABLE 6. MEAN CONCENTRATIONS (mg/1) OF METALS IN DIGESTED SLUDGES, 1973-74

SLUDGE SOURCE	NORTH TORONTO			POINT EDWARD			NEWMARKET			SARNIA		
SLUDGE TYPE	FERRIC CHLORIDE			ALUM			LIME			FERRIC CHLORIDE		
	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL
Ni	2.2	1.3	0.3	1.9	1.1	0.3	2.3	1.7	0.4	6.3	3.2	1.0
Zn	190	46	12	66.9	36.1	9.2	92.6	64.9	16.9	1570	540	173
Cu	82.7	14.1	3.7	47.2	37.1	9.6	21.6	10.2	2.7	112	29	9.3
Cr	40.5	14.1	3.7	8.0	3.3	0.9	3.8	2.3	0.6	24.8	8.5	2.8
Pb	88.	25.9	6.9	41	51.2	13.1	17	7.6	2.0	504	207	66
Cd	1.8	0.5	0.1	0.6	0.3	0.1	0.9	0.6	0.2	12.3	4.1	1.3
TOTAL SOLIDS %	6.25	0.90	0.24	6.90	3.70	0.94	12.2	5.92	1.54	16.19	3.93	1.27

TABLE 7. MEAN METAL CONCENTRATIONS (mg/kg TOTAL SOLIDS) IN DIGESTED SLUDGES, 1973-74

SLUDGE SOURCE	NORTH TORONTO			POINT EDWARD			NEWMARKET			SARNIA		
SLUDGE TYPE	FERRIC CHLORIDE			ALUM			LIME			FERRIC CHLORIDE		
	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL	MEAN	±SD	±95% CL
Ni	35	23	6	30	19	4.9	19	12	3.2	39	20	6.5
Cu	1340	200	54	641	201	52	184	61	16	700	130	42
Zn	3070	635	172	1010	438	112	766	347	91	9670	2890	930
Cr	664	236	64	128	53	14	33	17	4.5	150	45	15
Pb	1430	374	101	478	318	81	144	49	13	3050	1040	340
Cd	29	9	2.4	8.5	1.9	0.5	7.5	4.2	1.1	76.3	20.6	6.8

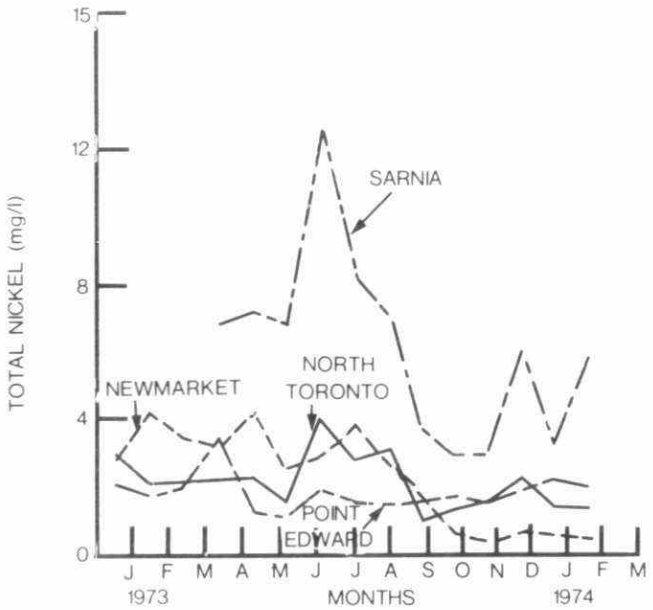

FIG.4 TOTAL NICKEL CONCENTRATIONS IN DIGESTED SLUDGES

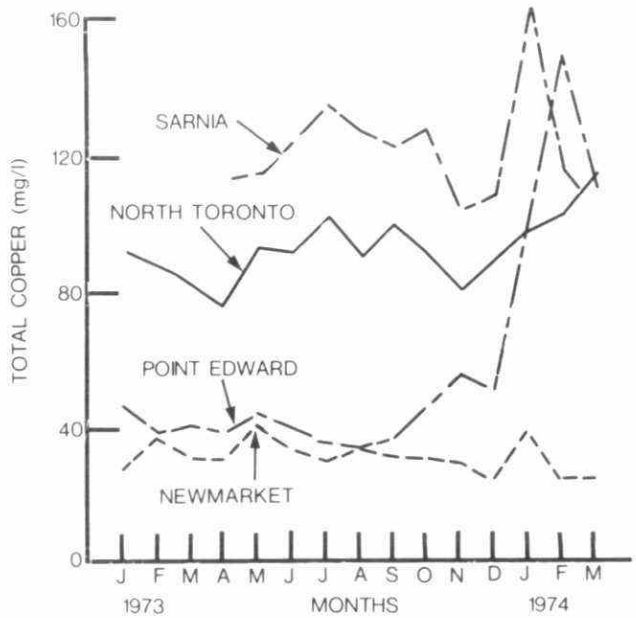

FIG.5 TOTAL COPPER CONCENTRATIONS IN DIGESTED SLUDGES

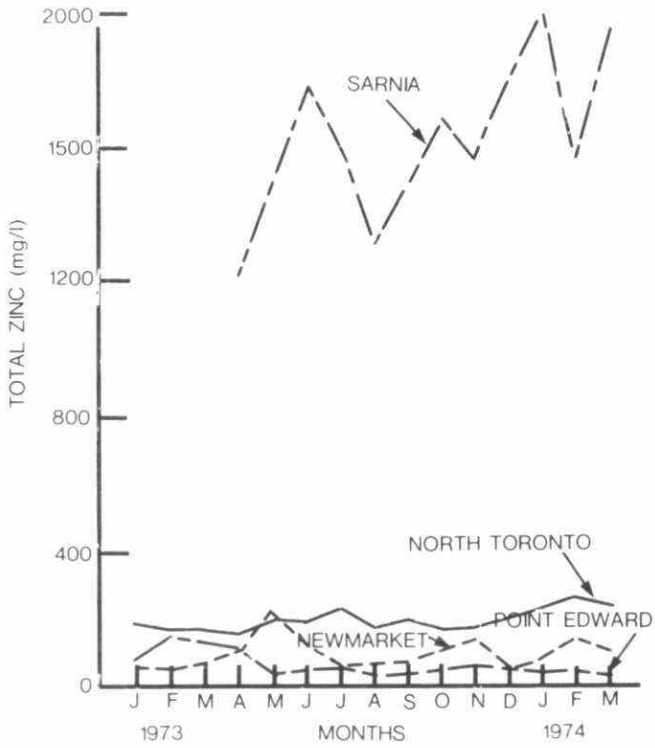

FIG.6 TOTAL ZINC CONCENTRATIONS IN DIGESTED SLUDGES

TABLE 8. ESTIMATED NUMBER OF SAMPLES REQUIRED TO PREDICT MEAN CONCENTRATIONS OF METALS WITHIN ± 10% OF POPULATION MEANS AT 95% LEVEL

SLUDGE SOURCE	NORTH TORONTO		POINT EDWARD		NEWMARKET		SARNIA	
SLUDGE TYPE	FERRIC CHLORIDE		ALUM		LIME		FERRIC CHLORIDE	
	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS	# REQ'D. ON WET WT BASIS	# REQ'D. ON DRY WT BASIS
Ni	140	172	134	160	219	160	103	105
Cu	12	9	247	39	89	44	27	14
Zn	23	17	116	75	196	82	47	36
Cr	48	51	68	69	147	106	47	36
Pb	34	27	612	177	85	46	67	47
Cd	31	39	100	20	178	125	44	29
SAMPLES IN THIS STUDY	60		61		59		40	

Overall total copper concentrations for these four plants ranged from 21.6 mg/l to 112 mg/l on the wet basis, and from 184 mg/kg total solids to 1340 mg/kg total solids on the dry basis (Tables 6 and 7). These overall means corresponded favourably with previous samples from these plants (VanLoon et al, 1973). In particular these four plants were below the average Cu content of some U.S. sludges (Sommers et al, 1973; Menzies, 1973; Dean, 1973), and closer to concentrations found in some European sludges (Pauly, 1971; Oden, 1970; Webber, 1972).

Monthly copper concentrations are plotted in Figure 5. Variations are evidently random in nature when treatment plants are operating at a steady stage. An increase in Cu concentrations was observed in the Point Edward sludge subsequent to lime-ferric chloride addition.

Copper concentrations were significantly correlated to total solids contents at the 99% level. Relative numbers of samples required for a ±10% precision on the overall means are presented in Table 8. Fewer samples are required on the dry weight basis for this precision.

Zinc is the most common heavy metal contaminant of sludges. Total zinc concentrations (Tables 6 and 7) closely parallelled those found in Europe (Webber, 1972; Pauly, 1971; Oden, 1970), but may be significantly lower than U.S. averages (Dean, 1973; Sommers et al, 1973). Predicted number of samples for ±10% precision in population means (Table 8) indicates the dry weight basis to be less variable than the wet weight basis. Zinc concentrations were correlated to the total solids contents in each sludge at the 99% level. A "good" sludge is reported as having zinc concentrations less than 5000 mg/kg solids (Menzies, 1973); the Sarnia sludge invariably exceeded that level during this study (9670 mg/kg solids).

Monthly zinc concentrations are depicted in Figure 6. No specific trends were observed in the data collected, and variations were random in nature.

3.2.2 Chromium, Lead, Cadmium

Chromium, lead and cadmium were selected for analysis because of their potential adverse affects on physiological systems. Overall mean chromium concentrations are presented in Tables 6 and 7. Data from these plants show levels much lower than some U.S. sludges (Sommers et al

1973) and similar to some Danish sludges (Pauly, 1971). This misrepresents Canadian sludges as being low in chromium as other cities such as Kitchener, Chatham and Aurora have given extremely high concentrations as reported by VanLoon et al (1973) and Abbott, (1971).

Increases were observed in the Cr content of the North Toronto sludge during the study as Figure 7 suggests. Deviations occurred randomly at the remaining treatment plants, showing some significant, but weak relationship to total solids contents. Chromium, like Zn, did not increase in concentration at the Point Edward plant.

No remarkable trends were observed in lead concentrations of these sludges (Figure 8) except at Point Edward. Increases at Point Edward coincided with $FeCl_3$ addition to the raw sewage. Lead concentrations were compared to values found elsewhere, and the overall means of this study were generally in the higher ranges reported. Overall mean lead concentrations, standard deviations and confidence limits are reported in Tables 6 and 7. Levels of lead and most other heavy metals are without doubt a function of the type of city from which samples are collected. Wide ranges in between these and between other sludges are readily evident (Abbott, 1971; VanLoon et al, 1973), Sarnia Pb levels (3050 mg/kg total solids) were twice as high as those found at North Toronto (1430 mg/kg total solids) on the dry weight basis. Mean composition of some U.S. and European sludges is considerably lower than these levels, but there may be a wide range from city to city (Sommers et al, 1973; Pauly, 1971; Menzies, 1973; Oden, 1970; Lisk, 1972).

Significant correlations were obtained between Pb levels and total solids in each sludge, with coefficients ranging from ±0.408 to + 0.917 and significant at the 99% level. Estimated numbers of samples for ±10% precision on overall population means indicate North Toronto to be the most uniform sludge even though the Newmarket plant has the lowest overall concentration. Again, fewer samples are required for the sample precision on a dry weight basis (Table 8).

Cadmium levels in these sludges behaved in a similar manner to most other heavy metals analyzed during the length of this study period. Overall Cd concentrations are reported in Tables 6 and 7. These are

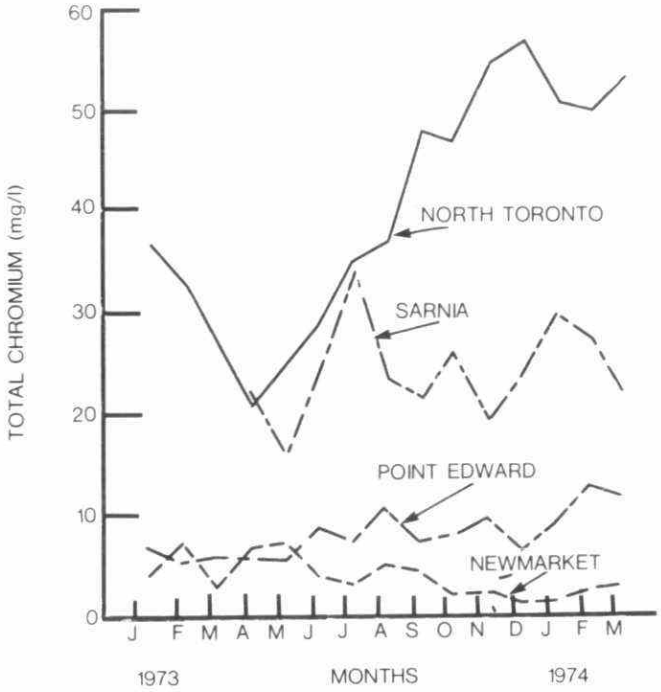

FIG. 7 TOTAL CHROMIUM CONCENTRATIONS IN DIGESTED SLUDGES

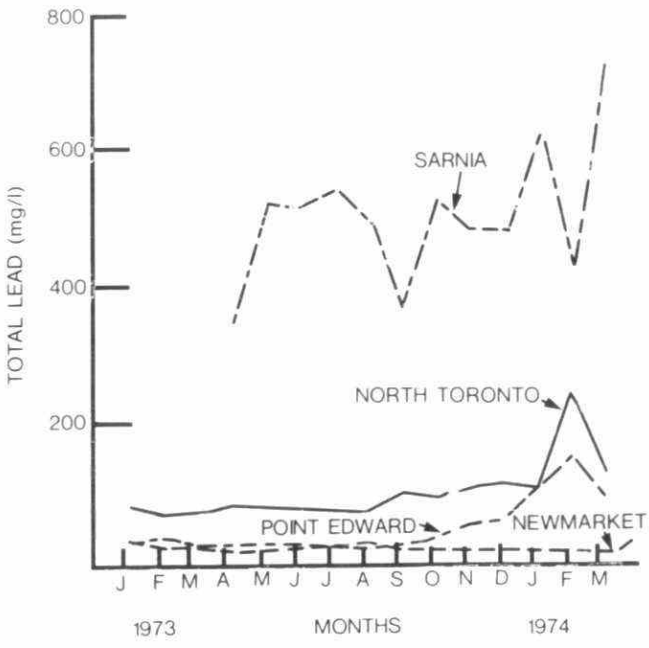

FIG. 8 TOTAL LEAD CONCENTRATIONS IN DIGESTED SLUDGES

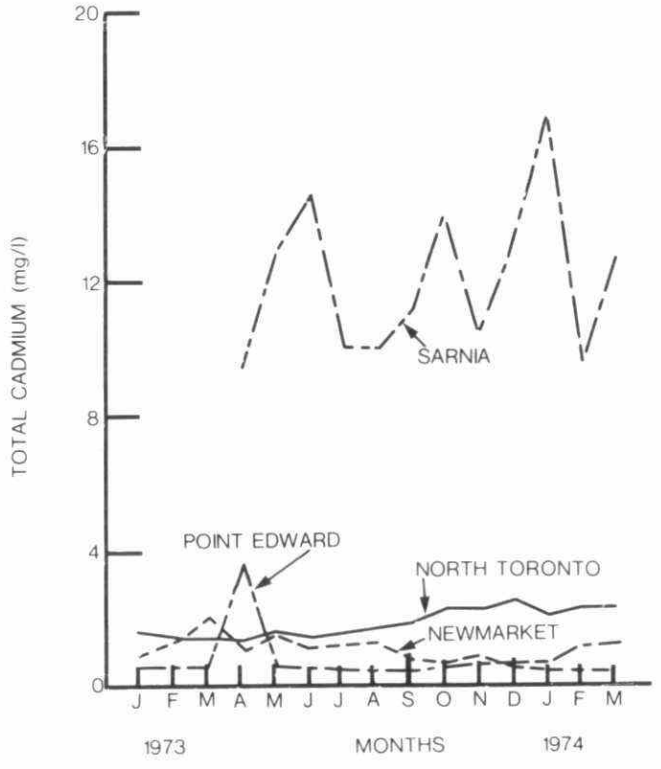

FIG. 9 TOTAL CADMIUM CONCENTRATIONS IN DIGESTED SLUDGES

again dependent on the locale from which samples are obtained (VanLoon et al, 1973; Pauly, 1971; Oden, 1970; Sommers et al, 1973). Monthly Cd concentrations are plotted in Figure 9. Sarnia sludge had the highest Cd levels found in this study (12.3 mg/l). Cadmium levels had the same magnitude of concentrations and variations as Ni results.

Significant correlation of Cd concentrations to total solids were obtained at the 99% level, except at North Toronto. The reduction in relative standard deviation with dry weight expression lead to greater precision in prediction of overall means as evidenced in Table 8.

3.3 Summary

The results of this study have demonstrated the variabilities in parameter concentrations which may be encountered in grab samples of sludges collected over a relatively long period. The small number of treatment plants (four) assessed are considered insufficient to categorize sludges from other Ontario treatment plants of similar size and type.

Total Kjeldahl nitrogen and total-P concentrations showed evidence of seasonal variation whereas NH_3-N did not. This study did not continue for a sufficient length of time to positively confirm seasonally dependent values, but it is highly unlikely that increases in TKN and total-P occurred by chance since they were observed at each plant. Seasonal nitrogen and phosphorous variations were not found in U.S. raw sewages (Schwinn and Dickson, 1972). Significant correlations were observed between TKN-N and total-P concentrations at each plant.

Estimation of the number of samples required to predict mean nutrient concentration within ±10% of population means was variable. No pattern could be observed in these predictions, and values depended on the parameter measured and the locale from which the samples were taken. Total-P was one parameter exhibiting a relatively high standard deviation, and this resulted in considerably more samples being required for this prediction; whereas, NH_3-H was more uniform. These findings suggest that nutrient parameters of special interest must be characterized at individual treatment plants to obtain reliable estimates of true population means and deviations. Only long term sampling can identify long term trends within sludge characteristics.

Heavy metal concentrations varied randomly except at Point Edward, where conversion from alum to lime + $FeCl_3$ resulted in the immediate increase in some specific heavy metals in the digested sludge. This fact makes prediction of maximum probable concentrations at individual treatment plants possible provided appropriate sampling programs can be designed.

Heavy metals at all treatment plants except North Toronto showed significant correlations to total solids contents. Again, this was particularly true at Point Edward, but at other plants correlation coefficients were sometimes of relatively low magnitude. Low magnitudes indicate a good deal of variation due to causes other than solids variation, i.e. independent random variation. However, expression of heavy metals concentration on a dry weight basis almost invariably yielded a higher relative precision in overall mean concentrations.

4 MICROBIOLOGICAL CONTENTS

Understanding of the bacterial contents in the digested sludges should provide useful information for better assessment of land application effects of such sludges. Efforts were made to study bacterial types and population densities of sludges collected from Point Edward, North Toronto and Newmarket plants.

4.1 Bacteria Types

In view of the continous spectrum of properties exhibited by the bacteria, it was decided to identify the sludge bacteria to genera only. The method of Cowan and Steel (1970) and of Bailey and Scott (1970) were used in the identification of digested sludge bacteria. Experience has shown they are not entirely satisfactory for sludge bacteria identification, because the original schemes were aimed at the identification of medical bacteria. Therefore, Bergey's manual (1957) was also used as supplement in the present work.

Table 9 summarizes the predominant types of aerobic heterotrophic bacteria found in three chemical sludges. They were Alcaligenes, Acinobacter, Flavobacterium, Aerobacter, Aeromonas, Pseudomonas and Escherichia.

TABLE 9. PRELIMINARY TAXONOMIC STUDY OF BACTERIA IN DIGESTED CHEMICAL SEWAGE SLUDGES, SPRING 1973.

POINT EDWARD ALUM SLUDGE		NORTH TORONTO IRON SLUDGE		NEWMARKET LIME SLUDGE	
Alcaligenes	90%	Flavobacterium	90%	Alcaligenes	90%
Flavobacterium		Acinobacter		Flavobacterium	
Acinobacter		Alcaligenes		Acinobacter	
Pseudomonas		Pseudomonas		Aerobacter	
Aeromonas		---		---	
---		Aerobacter		Enterobacteriaceae sp.	
Escherichia		Escherichia		Escherichia	
Bacillus					
Enterobacteriaceae sp.					

4.2 Bacteria-Densities

Densities of various bacteria in sludges were also investigated to give a quantitative picture of heterotrophic bacteria (Table 10). From June to September 1973, the concentrations of total aerobic heterotrophic bacteria varied from 7.5×10^9 to 4.1×10^{10} bacterial cells per 100 ml of sludge; total coliforms from 2×10^4 to 5×10^6; fecal coliforms from 1×10^4 to 5×10^5; and, fecal streptococci from 3×10^3 to 3.4×10^5. In all, coliform bacteria accounted for less than 0.1 percent of the total heterotrophic bacterial population in the digested sludge.

5 ORGANOCHLORINE PESTICIDES

Most common pesticides found in soils are chlorinated hydrocarbon pesticides. Eleven organochlorine pesticides were monitored weekly for the period of June 1973 to March 1974 in the digested sludges collected from North Toronto, Point Edward, Newmarket and Sarnia sewage treatment plants.

Table 11 summarizes the overall picture of the organochlorine pesticides in the municipal digested chemical sewage sludges over a period

TABLE 10. DENSITIES OF VARIOUS BACTERIA IN DIFFERENT CHEMICAL SEWAGE SLUDGES*

SAMPLING DATE	ALUM SLUDGE (POINT EDWARD)				IRON SLUDGE (NORTH TORONTO)				LIME SLUDGE (NEWMARKET)			
	HETEROTRO-PHIC BACTERIA (20°C)	COLI-FORM MF	FECAL COLI- MF	FECAL STREPTO-COCCUS MF	HETEROTRO-PHIC BACTERIA (20°C)	COLI-FORM MF	FECAL COLI-FORM MF	FECAL STREPT-OCOCCUS MF	HETEROTRO-PHIC BACTERIA (20°C)	COLI-FORM MF	FECAL COLI-FORM MF	FECAL STREPTO-COCCUS MF
JUNE 5, 1973	8.8×10^{9}	1.1×10^{6}	7×10^{4}	4×10^{4}	2.7×10^{10}	2×10^{4}	1×10^{4}	2×10^{4}	1.2×10^{10}	2.5×10^{6}	4.5×10^{5}	3.4×10^{5}
JULY 27 1973	7.5×10^{9}	8.7×10^{5}	1×10^{5}	2×10^{4}	2.2×10^{10}	9×10^{4}	3×10^{4}	1×10^{4}	3.2×10^{10}	7.5×10^{5}	1×10^{4}	5×10^{4}
SEPT. 5 1973	2.7×10^{10}	1.5×10^{6}	5×10^{5}	5×10^{4}	4.1×10^{10}	6×10^{5}	8×10^{4}	3×10^{3}	1.1×10^{10}	3×10^{5}	-	3×10^{3}
MEAN	1.4×10^{10}	1.2×10^{6}	2.2×10^{5}	3.7×10^{4}	3×10^{10}	2.4×10^{5}	4×10^{4}	1.1×10^{4}	1.8×10^{10}	1.2×10^{6}	2.3×10^{5}	1.3×10^{5}

* Expressed as number of bacteria per 100 ml of sludge.

TABLE 11. MEAN LEVELS OF ORGANOCHLORINE PESTICIDES (µg/l) IN DIGESTED CHEMICAL SLUDGES

ORGANOCHLORINE PESTICIDES	IRON SLUDGE N. TORONTO	ALUM SLUDGE PT. EDWARD	LIME SLUDGE NEWMARKET	IRON SLUDGE SARNIA
P, P'-DDT	1.33	0.77	1.12	2.70
O, P'-DDT	6.87	4.11	1.15	5.25
P, P'-DDE	7.18	3.68	2.81	20.77
P, P'-DDD	4.31	3.98	1.60	6.41
TOTAL DDD/DDE/DDT	19.69	12.54	6.68	35.13
α-chlordane	15.79	12.51	5.69	16.99
γ-chlordane	12.56	11.41	2.84	12.92
TOTAL CHLORDANE ISOMERS	28.35	23.92	8.53	29.91
Heptachlor	5.37	2.29	0.70	14.95
Heptachlor Epoxide	3.04	1.77	0.58	6.78
TOTAL HEPTACHLOR	8.41	4.06	1.28	21.73
Aldrin	2.03	1.09	0.70	9.40
Dieldrin	3.03	1.69	1.65	3.23
Lindane	1.48	1.16	0.63	3.22
TOTAL ORGANOCHLORINE PESTICIDES	63	45	20	103

of ten months. The sludge from Sarnia sewage treatment plant was found to have the highest level of total and individual organochlorine pesticides, followed by those from North Toronto, Point Edward, and Newmarket.

No significant seasonal trend was obvious for total DDTs in the various sludges studied. Industrial wastes could be the main source of pesticides as is evident from the values of Sarnia and North Toronto as compared to Point Edward and Newmarket sludges.

Considering the general practice of applying 10,000 gallons of liquid sludge per acre per year in Ontario, approximately 112,000 kg of sludge will be disposed on one hectare of land. Based on this figure, the total organochlorine pesticides which may be added from the sludges of Sarnia, North Toronto, Point Edward and Newmarket are 11.5, 7.0, 5.0 and 2.2 grams/ha respectively. These quantities are very low and should not pose environmental contamination hazard.

6 POLYCHLORINATED BIPHENYLS (PCBs)

Due to their low solubility in water and high affinity for lipids, PCBs, just like DDT, can be expected to be concentrated in sludges. They have been shown to accumulate in fish and aquatic invertebrates to levels of 75,000 times than that present in the water.

The levels of PCBs in digested chemical sewage sludges from four sewage treatment plants in Ontario for the period of June 1973 to March 1974 are presented in Table 12. The concentration of PCBs in the sludges varied from 74 to 1122 µg per liter of sludge (as Aroclor 1254) depending on the source of the digested sludges. The digested iron sludge from Sarnia sewage treatment plant had the highest concentration of PCBs (1122 µg/l). The next highest was the iron sludge of North Toronto sewage plant (214 µg/l), followed by the alum sludge of Point Edward sewage treatment plant (108 µg/l). The lowest concentration of PCBs occurred in the lime sludge of Newmarket (74 µg/l). The relatively high concentrations of PCBs in the digested chemical sewage sludge is quite surprising, as the raw sewage to most Ontario sewage treatment plants has a PCB concentration of less that 1 µg/l (Shannon, 1974)

TABLE 12. MEAN MONTHLY LEVELS OF PCBs (AROCHLOR 1254) IN CHEMICAL SEWAGE SLUDGES (µg/l)

SOURCE OF SLUDGE	NORTH TORONTO	POINT EDWARD	NEWMARKET	SARNIA
TYPE OF SLUDGE	IRON	ALUM	LIME	IRON
JUNE 1973	206.2	148.6	45.2	975.0
JULY 1973	170.7	128.2	106.1	1730.0
AUGUST 1973	224.0	97.3	133.5	1477.8
SEPTEMBER 1973	286.7	145.3	105.2	1511.7
OCTOBER 1973	205.5	87.5	84.5	1241.0
NOVEMBER 1973	228.3	88.8	73.5	954.7
DECEMBER 1973	216.8	66.3	45.7	822.0
JANUARY 1974	200.6	62.9	48.5	864.7
FEBRUARY 1974	195.2	118.0	53.0	830.2
MARCH 1974	207.8	135.1	43.3	811.8
MEAN	214	108	74	1122

The ability of PCBs to accumulate and concentrate in the digested sludge is probably due to their oleophilic character which enables them to be absorbed or trapped by the hydrophobic groups of lignins or humic substances in the digested sludge. Most lignins have been shown to have ability to combine with the oleophilic groups of the lipid material (Liu and Townsley, 1970). This would probably explain why sludges have a hundred to a thousand times higher levels of PCBs than the incoming raw sewage. Ahling and Jensen (1970) studied the levels of PCBs and chlorinated pesticides in one Swedish sewage treatment plant and found that the sludge had 2700 times more PCBs and 330 times more DDT than the incoming wastewater.

7 LIPIDS AND PETROLEUM HYDROCARBONS

Lipids and petroleum hydrocarbons are quite resistant to biodegradation. Lipids have been found in aerobic and anaerobic sewage sludges (Viswanathan, et al 1962; Kolattuckndy and Purdy, 1973). Gas chromatographic and infrared spectrometric techniques were used to study the levels of total lipids and petroleum hydrocarbons in sludges of Point Edward, North Toronto and Newmarket for the period December 1972 - September 1973.

7.1 Levels of Total Lipids

The concentrations of lipids in the anaerobic digested chemical sludges from three sewage treatment plants are given in Table 13, where the lipid concentrations are expressed both by volume (mg lipid/l wet sludge) and by weight (mg lipid/g dry wt sludge). The fluctuation of lipid levels with time suggests that the origin of these lipids was probably from industrial activities. Loehr and Navarra (1969) made hourly sampling of the sewage effluents over a period of 24 hours at Topeka waste treatment plant (Kansas) and found large fluctuations of grease concentration in the effluents between hourly samples.

It can be seen from Table 13 that the mean level of lipids in the liquid sludge from Point Edward plant was approximately fifteen times higher than those from the North Toronto and Newmarket treatment plants. On dry sludge weight basis, lipid content was about 19% from Point Edward

TABLE 13. LEVELS OF TOTAL LIPIDS IN DIGESTED CHEMICAL SEWAGE

SAMPLING DATE	ALUM SLUDGE (POINT EDWARD)		IRON SLUDGE (NORTH TORONTO)		LIME SLUDGE (NEWMARKET)	
	mg/l LIQUID SLUDGE	mg/g DRY WT. SLUDGE	mg/l LIQUID SLUDGE	mg/g DRY WT. SLUDGE	mg/l LIQUID SLUDGE	mg/g DRY WT. SLUDGE
19/12/72	10870	170	330	66	139	3.8
19/01/73	17750	227	720	8.5	1068	4.7
25/01/73	11580	177	420	5.4	130	5.3
01/02/73	13660	230	524	14.6	1130	5.6
09/02/73	10380	214	570	8.6	-	-
15/02/73	10270	203	880	13.7	1430	7.2
21/02/73	10400	197	800	11.3	1559	8.0
01/03/73	10110	197	560	9.5	620	8.0
15/03/73	12640	219	700	17.3	1428	6.5
21/03/73	8960	-	661	-	460	-
01/06/73	6580	142	220	3.1	70	0.6
24/07/73	4130	104	450	7.8	120	2.1
05/09/73	7910	194	1440	22.2	640	5.0
MEAN	10403	189	636	11	733	5

plant as compared to only 1.1 and 0.5 percent from North Toronto and Newmarket respectively.

7.2 Petroleum Hydrocarbon Concentrations

From the gas chromatograms, selected peaks were identified by the use of internal standards in separate runs. Petroleum hydrocarbons were detected in all three anaerobic digested chemical sludges. The sludge from the Point Edward plant had a petroleum hydrocarbon concentration of 7580 mg/l; among this hydrocarbon fraction, 32% (2420 mg/l) was n-alkane. The petroleum hydrocarbon concentration in North Toronto sludge was much lower, being 524 mg/l; 16% (83 mg/l) was n-alkanes. The lime sludge from Newmarket had the lowest petroleum hydrocarbon concentration, 434 mg/l; 14% (62 mg/l) was n-alkanes.

8 IMPLICATIONS OF AGRICULTURAL UTILIZATION

8.1 Utilization with Respect to Ammonium-N Content

The nutrient content of digested sludges is expected to become a more valuable commodity for agricultural fertilization as some nutrients are in shorter commercial supply than ever before. Ontario soils recommended to receive sludge applications are those requiring nitrogen, especially those cultivated for corn, grass, hay and commercial sod. It has been recommended that sludge disposal quantities to based on the amount of ammonium-N, and that this quantity be known within ±25% of its actual value in any sludge (Ontario Ministry of Agriculture and Food, 1974).

This study has shown that the NH_3-N concentrations do not demonstrate seasonal trends but vary randomly about population mean values at each treatment plant. The proportion of samples expected to have NH_3-N concentrations ranging between ±25% of the mean concentration has been calculated for each of the four treatment plants in Table 14.

The O.M.A.F. (1974) tentative guidelines reveal that a sampling program more thorough and precise than the present study would have to be carried out to obtain reliable estimates of the NH_3-N concentrations in digested sludges. A program is presently being carried out at Simcoe involving the development of reliable sampling techniques.

TABLE 14. PROPORTION OF SAMPLES WITH NH_3-N CONCENTRATION WITHIN ±25% OF MEAN.

SLUDGE SOURCE	MEAN NH_3-N CONC. mg/l	RANGE ±25% OF MEAN	PROPORTION OF SAMPLES WITHIN RANGE
North Toronto	744	558-930	91%
Point Edward	290	217-363	53%
Newmarket	292	219-365	42%
Sarnia	416	312-520	57%
MEAN %			61%

8.2 Utilization with Respect to Heavy Metal Content

Interim guidelines for the heavy metal content of digested sludges destined for disposal on agricultural land have also been developed by O.M.A.F. (1974). Sludge applications to land made on the basis of NH_3-N: metal ratios have been proposed. Sludges exceeding the minimum ratios proposed are considered suitable for use in agriculture; the others are not. Using the overall mean NH_3-N and heavy metals concentrations of the sludges in this study, overall ratios were calculated for sludges from each source. These ratios are presented in Table 15.

TABLE 15. OVERALL RATIOS OF NH_3-N:HEAVY METALS IN SLUDGES AND MINIMUM ACCEPTABLE RATIOS.

O.M.A.F. (1974) MINIMUM ACCEPTABLE RATIOS	PARAMETER	SOURCE NORTH TORONTO	POINT EDWARD	NEWMARKET	SARNIA
500	Cd	410	480	325	34
100	Ni	340	150	130	66
50	Pb	8	7	17	1
20	Cu	9	6	14	4
20	Cr	18	36	77	17
5	Zn	4	4	3	1

On the average, these calculations indicate that only five of twenty-four possible parameter/source combinations have acceptable ratios. This further suggests that these four sludges are unsuitable for agricultural utilization at normal nitrogen fertilization rates according to interim guidelines proposed by O.M.A.F. (1974).

9 CONCLUSIONS

An extensive study on the biochemical characterization of chemically precipitated digested sewage sludges was conducted at the Wastewater Technology Centre, Burlington, Ontario. From the results of this investigation the following conclusions have been reached:

1. Sludges from sewage treatment plants should be characterized on an individual basis since concentration differences were clearly evident among those plants studied.
2. TKN and Total P concentrations increased at each treatment plant over this study period. Seasonal variations were not evident in NH_3-N concentrations;
3. TKN, NH_3-N and Total P concentrations varied appreciably in digested sludges as compared to reported nitrogen and phosphorus variations in domestic raw sewage. The overall mean ranges of concentrations for TKN, NH_3-N and Total P were 1150 to 2510; 290 to 744; and 665 to 1420 mg/l respectively in all four sludges;
4. Heavy metal concentrations varied randomly. Specific trends observed at Point Edward did not represent steady state conditions;
5. Based on the proposed guidelines of the Ontario Ministry of Agriculture (1974), none of the sludges were suitable for agricultural utilization;
6. The populations of aerobic heterotrophic bacteria were relatively constant and their concentrations ranged from 7.5×10^9 to 4.1×10^{10} per 100 ml. Coliform bacteria accounted for less than 0.1 percent of the total heterotrophic bacteria in all cases;

7. Eleven organochloride pesticides were detected in all four sludges studied - the predominant pesticides were DDT, DDE, Chlordane and Heptachlor;

8. Normal sludge applications of 10,000 gallons/acre (112,000 kg/ha) on farm lands should contribute non-significant amounts of pesticides to the soil system;

9. Overall mean concentrations of PCBs in all four sludges ranged from 74 to 1122µg/1 (as Archlor 1254). Sludge from the Sarnia sewage treatment plant had the highest mean level (1122 µg/1) as compared to the lowest level of 74 µg/1 from the Newmarket plant.

10. Sludge from Point Edward, North Toronto, and Newmarket had petroleum hydrocarbon concentrations of 7580, 524 and 434 mg/1 respectively. Very high concentrations from Point Edward plant were unexpected and suggested abnormal industrial contamination.

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VIROLOGICAL INVESTIGATIONS ON SLUDGES FROM SELECTED ONTARIO SEWAGE PLANTS

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Ever since John Snow established the role of water in the spread of cholera, edidemiologists and microbiologists have recognized the health hazard posed by the presence of infectious agents in the environment. The shedding of enteroviruses into the environment was demonstrated by Paul and Trask (1) at Yale University when they showed that poliomyelitis patients excrete viruses in their stools. This set the stage for the virological examination of urban residential sewage and the early pioneering work was done by Melnick and coworkers at Yale. They (2) found that virus isolation rates were considerably improved if, instead of collecting a grab sample, a gauze-pad was suspended in the influent sewage for as long as 7 days and the swabs eluted with an alkaline balanced salt solution. This agrees with the later experience of others (3, 4) and the gauze-pad method is still employed as a simple, practical and sensitive method for monitoring grossly polluted waters. In their studies on sewage and sewage-contaminated waters, Melnick et al (5) were able to isolate enteric viruses frequently during the summer and fall months but only rarely in winter. The seasonal presence of enteroviruses in urban sewage in the temperate region is in agreement with epidemiological patterns of these viruses and has been confirmed by others (6, 7). The viruses isolated from sewage and related materials in various parts of the world include polioviruses, coxsackieviruses, echoviruses, reviruses and adenoviruses. All of these are pathogenic for man but the most significant observation on the dangers posed by sewage came not from the laboratory but from the field when a massive hepatitis epidemic occurred in New Delhi. Out of a population of about 1.5 million people who consumed sewage-contaminated water, over 35,000 persons became ill in a single month and there were 73 deaths. This

experience underlines the importance of ensuring that sewage treatment processes inactivate all the viruses present in the sewage before effluents or solid products are dispersed in the environment.

It has been estimated that urban areas discharge daily about 600 liters of sewage and 10 liters of wet sludge per person. Safe disposal of these enormous amounts of potentially dangerous materials should include efficient virus inactivation. The solid residues of sewage treatment viz. sludge should receive special attention since viruses show a marked tendency to adsorb to solids. In any sludge disposal or utilization programme, it is essential to guard against contaminating the environment with viruses and other harmful agents. Thus there is a clear need to determine whether viruses are present in sewage or sludge destined for use in agricultural operations. The extent of virus contamination has to be surveyed and practical monitoring methods as well as suitable standards developed.

This paper deals with the results obtained in a virus monitoring study of sludge and sewage conducted in the Virus Laboratory of the Ministry of Health in co-operation with the Ontario Ministry of the Environment and the Toronto Works Department. Financial assistance for this study was provided by the CORE committee.

MATERIALS AND METHODS

The water pollution control plants at Newmarket, Point Edward and Sarnia were studied during 1973. The Lakeview plant is also being monitored in 1974. The treatment plants in Toronto and Burlington were included as controls. The particulars regarding the plants are given in Table 1.

Specimens: Sludge samples were collected in approximately 100 ml volumes soon after the contents of the digester tank were well mixed. Digested sludge specimens had usually remained in the tank for 3 - 4 weeks while raw sludge samples were collected soon after the sludge was pumped into the digester. Sewage specimens were collected by suspending 16-ply gauze pads containing absorbent cotton in the sewage influent for 3 days.

Processing: The sludge and gauze-pads were extracted at pH 9,5 with the minimum amount of alkaline balanced salt solution. The sludge specimens were homogenised at high speed in the Omnimix while gauze-pads were placed in leakproof plastic bags with balanced salt solution and firmly kneaded for about 10 minutes. The extracts were centifuged and the clear supernatants treated with half the volume of chloroform overnight at $4^{o}C$ to destroy bacteria and other microbes which could affect the test. This procedure has been modified recently and the extracts are now treated with 10% fetal calf serum and passed through sterile millipore membranes (HA 0.45μ) to ensure that chloroform-sensitive viruses are not missed.

Virus Isolation: The aqueous extracts were inoculated several times into tube and bottle cultures of primary African green monkey kidney cells (AGMK) and human fetal diploid ling cells (WI-38). The inoculated cultures were observed for virus-induced cytopathic effects. When a virus was recovered, it was examined under the electron microscope for group identification and by neutralization tests against intersecting pools of specific antisera to determine the type. In the absence of virus-specific CPE, the cultures were also examined by the haemadsorption and interference methods for noncytocidal viruses. Most of the inoculated cultures were also screened by electron microscopy.

When polioviruses were isolated, additional tests for genetic markers and antigenic differentiation were carried out to distinguish between virulent and vaccine strains.

RESULTS

1. Effect of chloroform treatment: Three separate 10 ml portions of a pooled virus-negative sewage extract were mixed with 1, 5 and 10 ml respectively of chloroform. After 18 hours at $4^{o}C$, the chloroform-free aqueous phases were inoculated with standard bacteriological media and into AGMK cell cultures. The samples treated with 5 and 10 ml of chloroform were free of bacteria and other contaminants. It was concluded that treatment with a final concentration of 33% chloroform was adequate for the decontamination of specimens for entervirous isolation.

Another experiment was carried out to determine the stability of an enterovirus in presence of chloroform by treating $10^{6}TCID_{50}$ per

TABLE 1

PARTICULARS OF SEWAGE PLANTS MONITORED

		Daily Throughput (Millions of Gallons)	Phosphate Removal Treatment
Burlington	Extended Aeration	10	Alum
Lakeview	Activated Sludge	20	
Newmarket	Activated Sludge	3	Lime
North Toronto	Activated Sludge	8	
Point Edward	Primary	0.57	Lime-Iron
Sarnia	Primary	8	$FeCl_3$
Toronto (Main)	Activated Sludge	180	None

TABLE 2

ELUTION OF ENTEROVIRUSES FROM SEWAGE SLUDGE

Specimen	pH	Virus Recovered ($TCID_{50}$/0.2 ml)*
Virus Control	7.2	4.25
Sludge Preparation 1	Unadjusted (6.0)	0
Sludge Preparation 2	6.5	0
Sludge Preparation 3	7.5	0
Sludge Preparation 4	8.5	1.75
Sludge Preparation 5	9.5	3.75

* log to the base 10

ml with an equal volume of chloroform for 18 hours at 4°C. Both the treated sample and untreated control gave identical titres of 10^6TICD$_{50}$ per ml indicating that chloroform does not affect the virus.

2. Optimum pH for elution of enteroviruses: Identical amounts (10^6TCID$_{50}$) of poliovirus type 1 were added to five separate 10 ml portions of virus-negative sludge. Each mixture also received 2 ml of balanced salt solution and sufficient 1N NaOH to adjust the pH to levels indicated in Table 2. The mixtures were homogenized in the Omnimix and the supernatants treated with chloroform and titrated for virus in AGMK cell cultures. The results showed elution to be most efficient at pH 9.5. Raising the pH to 10.5 in a subsequent experiment reduced virus titres. A pH of 9.5 was chosen as the optimal level for virus elution.

3. Concentration procedures: Various concentration procedures were compared by adding approximately 10^6TCID$_{50}$ of poliovirus type 1 to 2 litre volumes of clarified sewage and processing by the different methods. The results are given in Table 3. Ultrafiltration through an Amicon PM30 membrane gave a 20% recovery of the added virus if the membrane was washed. In other experiments with clarified river water, we have found that the recovery rates can be raised to 50% by adding 2.5% fetal calf serum and 0.0025M disodium EDTA to the material. Filtration of the virus-contaminated clarified sewage through a sodium alginate membrane and subsequent solution of the alginate in 3.8% sodium citrate led to a 33% recovery of the added virus. The talc-celite method recently described by Sattar & Westwood (8) also gave comparable yields. Our experience with the polyelectrolyte PE-60[9] has been disappointing. We are now investigating the efficacy of these methods on composite sewage samples. In the case of small volumes of sludge or gauze-pad extracts, concentration methods are of limited value.

4. Efficiency of virus isolation procedures: There are two ways to assess the efficiency of the procedures. The first is to determine the recovery rate of added virus. Virus added to digested sludge is quickly adsorbed to the solids and can be recovered only by extraction at pH 9.5. The results in Table 2 show that when 10^6TCID$_{50}$ of poliovirus type 1 was added to 10 ml of virus-negative sludge, 30% of the added virus was

TABLE 3

RECOVERY OF POLIOVIRUS ADDED TO CLARIFIED SEWAGE BY VARIOUS CONCENTRATION METHODS

Method	Equipment	Concentration Factor	% Virus Recovery
Ultrafiltration	Amicon with PM30 Membrane	50	20
Ultrafiltration	Sartorius with SM11733 Membrane	50	30
Sodium Alginate Membrane*		200	33
Talc-celite*		50	33
PE-60*		50	1

* Experiments carried out with 500 ml volumes

TABLE 4

VIRUS ISOLATION RATES FROM SEWAGE AND RELATED SPECIMENS

	Virus Isolation Rate	%
Sewage	48/124	38.7
Raw Sludge	12/92	13
Digested Sludge	1/111	0.9
Other	0/26	
	61/353	

recovered at pH 9.5. This falls just outside the experimental error of the titration technique and may be considered acceptable since we have no means of knowing what proportion of the adsorbed virus is irreversibly bound. In other experiments using $10^6 TCID_{50}$, recovery rates up to 50% have been obtained but the results with smaller amounts of virus were poorer.

Results of retesting specimens is perhaps an equally valid measure of efficiency especially since complex adsorption effects influence the results of recovery experiments. In this study, all specimens received during the summer and fall were routinely retested, twice in tube cultures and at least once in Falcon bottle cultures inoculated with maximum tolerated inocula. Only 12 specimens out of 140 negatives yielded a virus on retesting. An additional 4 specimens which yielded a virus in the first test yielded a second virus on retesting.

5. Virus isolation from sewage and sludges: During 1973, we examined 353 specimens between April and December. These included 124 sewage specimens, 109 raw sludge specimens, 111 digested sludge specimens and 26 effluents. The virus isolation results are summarized in Table 4. It can be seen that raw sewage contained virus almost 40% of the time while 13% of the raw sludges yielded virus and only 1 out of 111 digested sludges showed the presence of virus. In 1974, 267 specimens which included 115 sewage samples and 152 sludges have been examined. Viral agents have been recovered from 8 specimens but these have not been identified. Retesting is not complete in the case of many of these specimens.

Virus isolation data from sewage and sludge in respect of individual sewage plants are given in Table 5. Viruses were isolated from one-quarter to one-half of all sewage specimens collected from each plant during this period. It was also found that in the case of each plant, the isolation rates were much higher during the months of August and September, months of peak enterovirus prevalence in Ontario: enteroviruses were rare or absent in colder months when they were not detected in the community either. Viruses were found in the raw sludge from all the sewage plants, though much less frequently than in the case of

TABLE 5

VIRUSES FROM INDIVIDUAL SEWAGE PLANTS

Sewage Plant	Virus Isolations From				
		Sludge			
	Sewage	Raw	Digested	Other	Total
Burlington	5/23[1]			0/11	5/34
Newmarket	7/18	4/21	0/27	-	11/66
North Toronto	-	0/1	0/6	0/14	0/21[2]
Pt. Edward	15/30	2/35	0/36	0/1	17/102
Sarnia	12/31	6/35	1/42	-	19/108
Toronto	9/22	-	-	-	9/22
Total	48/124	12/92	1/111	0/26	61/353[3]

1. Number of specimens containing virus / Total number of specimens tested.
2. Raw and digested sludge from the North Toronto plant and run-off waters from experimental plots in the University of Guelph supplied by Professor R.A. Johnston.
3. The figures do not include 91 treated river water specimens from which 7 parainfluenza viruses were isolated.

sewage. The chance of detecting enteroviruses from raw sludge was again greatest during the enterovirus season. In the case of the digested sludge, however, virus was found only once in 111 tests, in a sample of digested sludge obtained from the Sarnia sewage plant during August.

The monthly virus isolation pattern for 1973 (April to December) is given in Table 6. Of the sixty eight isolates, 14 were non-polio entereoviruses (1 Coxsackie A9, 12 Coxsackie B4 and 1 Coxsackie B5) as well as 17 enteroviruses which have not yet been identified. Of the 45 enterovirus isolates, 40 were isolated between July and November and in fact 27 or 60% of these isolates were obtained in just two months, August and September, which agrees with the well documented summer-fall prevalence of these viruses in Ontario. In addition to the enteroviruses, 16 reoviruses were also isolated.

Particulars of the various enteroviruses isolated from the different types of specimens are given in Table 7. Sewage specimens yielded 13 polioviruses while raw sludge contained a poliovirus only on one occasion. None of the digested sludge specimens contained polioviruses. The isolation of so many polioviruses was disturbing and it was considered important to investigate whether the isolates were vaccine strains or virulent strains.

T marker tests have been carried out in the case of 12 isolates and the McBride antigenic marker in the case of three One poliovirus type 2 isolate resembled virulent virus in both tests while a poliovirus type 3 strain resembled vaccine virus in both tests. A third isolate was of intermediate character in the T marker test and did not resemble the vaccine strain in the antigenic marker test. Of the remaining 9 isolates for which T marker results are available, 6 were vaccine-like and 3 appeared to be of intermediate character. Further tests are in progress.

COMMENTS

Viruses such as polio, hepatitis as well as the many antigenic types of entero-, adeno- and reoviruses are shed in large amounts in the body secretions and excretions of infected persons. Even in the absence of disease, each infected person excretes thousands of infectious units

TABLE 6

MONTHLY PATTERN OF VIRUS ISOLATION
FROM SEWAGE AND RELATED SPECIMENS
APRIL - DECEMBER, 1973

Month	Number of Virus Isolations					
	Enteroviruses					
	Polio	Non-Polio	Untyped	Total	Reoviruses	Total
April	0	0	0	0	0	0
May	1	0	0	1	0	1
June	1	0	0	1	0	1
July	1	1	2	4	0	4
August	6	3	6	15	2	17
September	3	8	1	12	1	13
October	1	1	2	4	2	6
November	1	1	3	5	9	14
December	0	0	3	3	2	5
Total	14	14	17	45	16	61

TABLE 7

ENTERIC VIRUSES ISOLATED FROM SEWAGE AND SLUDGE

Virus	Number of Isolates			
	Sewage	Raw Sludge	Digested Sludge	Total
Polioviruses	13*	1	0	14
Coxsackievirus A9	1	0	0	1
Coxsackievirus B4	8	4	0	12
Coxsackievirus B5	1	0	0	1
Unidentified Enteroviruses	12	4	1	17
Reoviruses	13	3	0	16
Total	48	12	1	61

* Four specimens yielded additional enteriviruses on retesting. They are being investigated.

of the virus daily and in urban areas the sewage system probably recieves many million infectious units of one virus or another each day. At our northern latitude, enterovirus infections are widely prevalent in the population and viruses are regularly found in the sewage during the warm months of summer and fall. Other pollutants in sewage would also affect virus isolation and only viruses which withstand the adverse conditions are likely to be detected.

Viruses show a marked tendency to adsorb to many types of particulate materials and therefore viruses entering sewage would eventually be deposited in the sludge. This is likely to be especially true of sewage plants which remove phosphates by precipitation. Viruses adsorbed to the precipitated phosphates or other solids are likely to be eluted under appropriate conditions since adsorption per se does not lead to virus inactivation and furthermore is a reversible physico-chemical process. The leached viruses would be carried by run-offs and if sewage sludge were applied to land, there is a definite possibility of contaminating surface and subsoil water in the absence of suitable safeguards. This would remain an academic problem if waste disposal had not assumed today's enormous proportions.

Polioviruses, which were predominant not too long ago, have been eradicated almost completely in most temperate zone countries including Canada with the help of effective vaccines. The presence of polioviruses belonging to all three types at one time or another in sewage from all areas investigated was therefore disturbing, particularly since live virus vaccine is not routinely used in Ontario; in addition, sporadic cases of poliomyelitis have become more frequent in recent years showing that virulent strains of the virus are circulating in the community. The results of genetic and antigenic characteristic tests indicate that many of the isolates are attenuated strains, probably vaccine strains imported from areas using live vaccines.

The non-polio enteroviruses isolated in this study viz coxsackie A9, B4 and B5 viruses are all recognized human pathogens responsible for a variety of syndromes ranging from trivial common-cold-like illnesses to serious syndromes like pericarditis and meningitis or even encephalitis. The predominance of coxsackie B4 virus among the non-polio

enteroviruses agrees with our clinical results. The survival of many coxsackie B4 strains in raw sludge is an indication that the results with polioviruses cannot be extrapolated to the other viruses and this aspect should be closely examined. The absence of echoviruses among the isolates could be due to their being prevalent only at a very low level or not at all in 1973; the picture could look very different in other years, especially during one of the frequent echovirus epidemics.

The hepatitis viruses A (infectious hepatitis) and B (serum hepatitis) are very important from the point of view of sewage and sludge examinations. Hepatitis A virus is perhaps of greater significance since it is known to be fecally excreted but our ability to detect this virus, which has an autumn-winter prevalence, is at present limited to finding human infections. When a detection method becomes available, our views on the health hazards associated with sewage and sludge might change if the hardy hepatitis A virus is frequently found in materials free of other easily detected viruses. The technology is more advanced in the case of hepatitis B viruses in that reliable methods are available for the immunologic and electron microscopic detection of Australian antigen which is a characteristic produce of this virus. There is some question as to whether this virus is fecally excreted although water-borne spread and oral route of infection have recently been strongly implicated. It would thus seem advisable to screen materials for evidence of the presence of hepatitis B virus.

In the present study, 48 out of 124 (40%) raw sewage specimens contained viruses. This might apppear to be a low virus isolation rate compared to some other studies but it must be emphasized that approximately 50% of our specimens were obtained during cold months (April to June, November to December) when enteroviruses were not prevalent and that the majority of the sewage plants serviced small communities with fairly uniform living standards, the Toronto specimens accounting for less than a fifth of the total. It should also be noted that plants included in this study did not receive purely residential sewage and the effects of chemicals present in industrial effluents have also to be considered. Collection of some of the specimens, for technical reasons,

from settling tanks rather than the sewage inlet might also have contributed to low isolation rates. It is interesting, however, that the sludge contained virus less often digested sludge being almost virus-free. The 1973 results are thus quite encouraging from our point of view but it should be mentioned that 1973 was a year of generally low enterovirus prevalence. The situation in a high prevalence year, expecially during a widespread epidemic such as caused by echovirus Type 9, could be quite different. The possible effect of practical methods for the detection of hepatitis viruses on these conclusions have already been mentioned.

CONCLUSIONS

It can be said guardedly that spreading sludge probably poses only a low level virological hazard. It is, however, unwise to make a definite judgement since a) 1973 was a year of low virus prevalence, b) the disposal system has not been subjected to the stress of large scale demand and c) the picture could look very different when we have practical methods for detecting hepatitis A and B viruses.

The most reasonable approach would appear to be to intensify the surveillance so that the preliminary conclusions can be confirmed and to investigate the problem of routine monitoring by designing a practical collection method for field use and improving extraction and assay methods.

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REGULATORY ASPECTS OF SLUDGE UTILIZATION ON LAND

by

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The amendments to Regulation 824, under the Environmental Protection Act introduced with respect to processed organic waste, not ontly designated and defined processed organic waste, but also established guidelines for the establishment and operation of organic waste sites.

The uncontrolled disposal of sludges onto land in the past has caused serious environmental problems and the the requirement under the Canada/U.S. Agreement for tertiary treatment at most pollution control plants in the Great Lakes Basin, and the consequent increase in sludge volumes, the need for adequate controls has become more imperative.

The controlled application of sludges back onto the land provides a valuable source of nutrients to the agricultural community and with world markets, especially in phosphorus, being most uncertain, sludges are now looked upon as an excellent and economic source of these necessary elements.

In essence, the processed organic waste program means that any hauler engaged in hauling and land utilization of sludge must have a Certificate of Approval for his system, which includes the hauling and spreading equipment; plus appropriate Certificates of Approval for the necessary number of sites for each sewage treatment plant, before he will be in a viable position to enter into a contract with that plant.

The internal processing of forms will require that adequate areas of land be available and investigated prior to any contractual arrangements so that this will ensure maximum control over the efficient use of this resource asset.

The Certificate of Approval for a system will be issued on the basis of the hauler's experience, the hauling equipment he has available, or intends to obtain, plus the spreading equipment; and, an adequate knowledge of spreading techniques in order to ensure that the sludge is spread properly. This certificate would be issued for a period of up to one year

and would have to be renewed annually, subject to his ability and willingness to meet the requirements and guidelines.

The site selection would be most critical, and would be arrived at utilizing data with respect to the quantities and quality of sludge involved along with an analysis of the soil on the site, and the crop. With the information that would be available, the site certification would be issued and would include statements which would show specifically the number of cubic yards of a specific quality of sludge that could be spread per acre per year. The records which would be kept by the pollution control plant, plus the operating records kept by the hauler, would be scrutinized by the Ministry to ensure that the conditions of the certificate were being complied with.

Site acceptance would involve not only the necessary physical characteristics as covered in the guidelines, (see Appendix) but a soil sample analysis in order to establish background levels of nutrients and metals, to ensure that the site was satisfactory for sludge application.

A continual monitoring program would be established at all sites in use and would involve at least one soil sample per year, along with crop samples which would be analyzed for heavy metal and nutrient uptake.

Should any undesirable build-up start to occur and pass limits established in the guidelines, an immediate stop order would be issued with respect to this site and activities would cease immediately.

In connection with this, the hauler would be required to have a number of alternate sites readily available to handle such emergency procedures. The results of these various analyses would be part of an ongoing monitoring and control program associated with processed organic waste and would be used to re-evaluate and establish new guidelines as time goes on and new facts and knowledge become available.

There has been a very close liaison with experts in the agricultural community in establishing the guidelines with respect to sludge additions and this program approach is based on the best knowledge available, plus ultimate protection of the environment including, of course, the food producing lands.

Guidelines for sludge utilization have been developed and refined over the past year by an Ad Hoc Committee and these are presently being finalized and approved by the participating government agencies. As soon as this is completed they will be available for distribution and will provide not only the limiting quantities and qualities but will relate the sludge application directly to existing environmental and ecological conditions and acceptable known levels.

It is felt, that using these guidelines, the built-in safety factors will ensure that no permanent damage or degradation will result from this activity, however there is always a possibility of some error or accident occuring, and this gives rise to some speculation with respect to legal responsibilities and authority.

If for instance, a farm was urged to use sludge as a source of nutrients by both environment and agriculture, and some adverse effects did occur with respect to the degradation of the land or crops either through lack of ability to analyse or lack of control in spreading who would be the responsible party? What sort of financial arrangement would be made with this individual in order to protect him?

It is also possible to utilize sludge on land with certain crops, and thin in the future, when the crop changed to another more sensitive product, discover that the land would not be usable for this specific purpose. This again brings up a point as to who would be responsible, and whether some machinery should be set in motion to document all these cases and have this information available to any prospective buyer.

Some other implications from the controlled use of sludge may also come to light, and if, as time goes on, it is found that the restrictions must be even more severe, it is possible that this type of utilization program will become too costly for the public and the Province to bear, and we must revert to a straight disposal type of operation thereby wasting this potential resource.

Our approach in this matter is to proceed slowly, and hopefully develop new limitations as time goes by which will make this utilization program more attractive.

The overall effects of these regulations and guidelines will involve three groups, the hauler, the water pollution control plant operator, and the site owner in the following manner.

The sludge hauler must undoubtedly take a more professional attitude towards his job. He will be required to utilize better and more specialized equipment for hauling and/or spreading: to take time to find and investigate acceptable sites; to undertake longer haul distances to acceptable sites; to allow for longer time at the site for spreading due to stricter spreading guidelines; and as a result, to be more careful in bidding on contracts to allow for increased costs of operation. The nature of the problem will also require better relations between the haulers and the rural community with an eye towards working together. This should result in the utilization of processed organic waste in an environmentally acceptable manner while weeding out unacceptable haulers.

The water pollution control plant must allow for longer lead times in negotiating hauling contracts and due to the increasingly strict control of the haulers, be prepared to pay increased costs for disposal.

Perhaps there is a need to acquire tracts of land as part of the capital outlay for new plants. There is also the onus on the plant operator for greater "quality control" of the processed organic waste allowed to be hauled from the plant which in turn required strict enforcement of industrial waste effluent by-laws to reduce/eliminate the possibility of producing an unacceptable processed organic waste for utilization. Again, good public relations with the rural community is of utmost importance.

The site owner may in effect reap all the benefits from the utilization of sludge on land. Apart from being a monor source of ammonia/nitrogen fertilizer and organic matter, as a soil conditioner to increase aeration and water retention for poor soils, processed organic waste is a valuable and "free" source of phosphorus which at the present time is in limited supply. As well, the site owner in some areas may receive some revenue for the use of his land.

The restrictions on land applications of sludge also direct some thought towards the treatment efficiencies of pollution control plants. For example, the more efficient the treatment plant gets with respect to producing a good effluent to a receiving water body, the worse the sludge becomes with respect to the materials, including heavy metals, that are concentrated in it. As this progresses, the sludge does in fact become more difficult to use because of the build-up of these materials and ultimately we reach a point where the sludge becomes completely unusable on land. It is possible now, that for certain sludges, even one light application would increase background levels of heavy metals beyond the background limits presently contained in the guidelines. Certain other treatments being investigated by the EPA in the U.S.A. are directed towards an in-plant treatment which tends to remove the nutrients in the form of phosphorus and ammonia compounds leaving a concentrated sludge which would be relatively high in heavy metals and this sludge would require strict disposal guidelines to prevent use on farm land.

This would however, make available the nutrient content of the sludge for the agricultural community, without the grave concern for the heavy metal content.

With respect to some of these difficulties, almost $200,000.00 worth of field laboratory studies are being funded in connection with the Canada/Ontario Agreements with respect to Great Lakes Water Quality, and the data being gathered from these various sources will be of extreme value in answering such questions as:

- does the metal and nutrient value of sludge vary or are we using faulty sampling techniques
- can other "in plant" methods be employed to smooth out the variations or will some additional treatment procedure be employed to "mine" the sludge for metal extraction
- can the nutrient value be extracted and leave only a highly "toxic" residue which can be "disposed" of acceptably

Another approach, which is being investigated quite strenuously is that of restricting even further, the quality of industrial waste

effluents entering our treatment systems. The only means of combatting this problem may be to reduce the concentrations of effluents generated by industry, either by further improvement of the processes involved or by in-plant treatment to remove the heavy metals before the effluents reach our sewer systems.

What happens if something goes wrong? If, not through the negligence of the hauler, a site should for some reason become unusable for present or future agricultural use, should the owner of the water pollution control plant be liable for damages as a result of the quality of the processed organic waste?

A compensation fund may be required, based on a surcharge per cubic yard of processed organic waste hauled from the water pollution control plant, to compensate for any damages which might occur due to processed organic waste quality or hauler error negligence. Another alternative might be the requirement of posting a bond by the hauler to cover any eventualities.

By no means do we have the answers to all these problems, however the co-operative interministerial approach should put us in a position where we can investigate this program thoroughly and at the same time maintain necessary protective measures so as not to degrade our environment.

APPENDIX - SITE PROPERTIES

1. Site Location

1.1 The site should be removed from surface water courses. The minimum distance between the site and the surface water course should be determined by the land slope as follows:

Max Sustained Slope	Minimum Distance to Watercourse	
	For processed organic waste application during May to Nov. inclusive.	For processed organic waste application during Dec. to Apr. inclusive
0 to 3%	200 feet	600 feet
3 to 6%	400 feet	600 feet
6 to 9%	600 feet	No processed organic waste to be applied.
Greater than 9%	No processed organic waste to be applied unless special conditions exist.	No processed organic waste to be applied.

1.2 The site shall be at least 300 feet from individual human habitations.

1.3 The site shall be at least 300 feet from water wells.

1.4 The site shall be at least 1,500 feet from areas of residential development.

1.5 No spreading shall be done when there is more than 3 inch frost or a solid ice layer on the surface of the soils, particularly when there is no snow cover.

1.6 Above values are for rapid to moderately permeability. For moderate to slow permeability the distances should be doubled and spreading suspended during March and April when run-off is expected.

1.7 In Northern Ontario suspend spreading on moderate to slowly permeable soil during April and May.

1.8 The ground water table during processed organic waste application should not be less than 3.0 feet from the surface for

soils with moderate to slow permeability. For soils with rapid to moderately rapid permeability the ground water table should be not less than 5.0 feet from the surface.

2. Land Characteristics

2.1 The land slope and soil permeability will determine the time of the year that processed waste may be applied, as follows:

Max Sustained Slope	Soil Permeability**	Allowable Duration of Application	
		Southern Ontario	Northern Ontario
0 to 3%		12 mon/yr	12 mon/yr
3 to 6%	Rapid to moderately rapid	12 mon/yr	12 mon/yr
	Moderate to slow	10 mon/yr (May to Feb.)	9 monyr (June to Feb.)
6 to 9%	Rapid to moderately rapid	7 mon/yr (May to Oct.)	6 mon/yr (June to Oct.)

** Soil permeability classification shall be in accordance with Tables 1 and 2 of the Ministry of Agriculture and Food's publication entitled "Drainage Guide for Ontario" (see Appendix 1). The type of soil should be determined with the use of County Soil Maps available through the Ministry of Agriculture and Food.

3. Site Management

3.1 When sludge is applied to agricultural land, the land is to be for those crops specified in these Guidelines. These restrictions on land use shall apply for six months from the date of application.

3.2 The boundaries of the site shall be marked (e.g. with stakes at corners) so as to avoid confusion regarding the location of the site during processed organic waste application, or during the taking of soil or crop samples. The markers should be maintained until the end of the current or subsequent growing season, whichever is applicable.

3.3 Soil tillage and processed organic waste application should, where possible, follow the contours of the land (to maintain a contour furrow system). Passage of processed organic waste spreading vehicles over the land should be minimized to reduce the compaction of the soil (e.g. the allowable processed organic waste application rate in cu yds/A/yr could be achieved after one or two passes.

3.4 Special precautions may be required where the possibility of localized surface water run-off problems exist.

3.5 Where processed organic waste application is carried out by tank truck, untiled land should be given preference to tiled land. Where tiled land is used the processed organic waste hauling contractor should request instructions from the landowner, with regards to minimizing the possibility of damage to the tile system.

4. Processed Organic Waste Application Rates

4.1 The processed organic waste hauling contractor shall adhere to the application rate (in cu yd A/yr) specified in the Certificate of Approval issued by the Waste Management Branch of the Ministry of the Environment. The suitability of processed organic waste application rates may, if required, be monitored by soil analyses and/or crop analyses. The collection of soil or crop samples shall be the responsibility of the Waste Management Branch.

4.2 The processed organic waste shall be spread uniformly over the surface of the land.

4.3 The water pollution control plant operating agency is to keep records of the location of all sites used for the disposal of its processed organic waste and the processed organic waste quantities disposed of at each site, each week (e.g. volume of processed organic waste in cu yds, and weight of processed organic waste solids in tons). The operating agency shall ensure that at least every 3 months, samples of the processed organic waste are submitted for thorough analysis (e.g. total solids, volatile solids, pH, nitrogen, phosphorus, potassium, either extractibles, heavy metals, etc.).

AGRICULTURAL USE OF SLUDGE

by

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Historically, man has used the enormous capacities of land, air and water as media for the disposal of his wastes. He was overly impressed with primary sedimentation as an initial treatment of sewage wastes; extended and forced aeration reduced further the biochemical oxygen demand. He also had a laboratory exercise to supply numbers and to evaluate the treatment process.

A day came when the primary processes were no longer adequate. The lowering of the biochemical oxygen demand and the removal of organics were not sufficient. We recognized that there were hidden dangers because the highest degree of waste treatment was not sufficient to prevent the growth of many organisms at all trophic levels. Water was unfit for human consumption, for recreational use or for fish production. In short, we rejected the phrase: the solution to pollution is dilution. Our vocalulary added new phrases: ecological impact, quality of the environment, effluent and affluent society, tertiary treatment, and many others.

WASTES ON LAND

Waste disposal on soil is as old as the problem of waste disposal. The first irrigation system designed primarily for sewage disposal began in 1559 in Prussia and operated for more than 300 years. In England a Royal Commission on Sewage Disposal (1859) recommended the application of town sewage to land as a means of avoiding river pollution. The Melbourne, Australia, Board of Works Farm occupies more than 25,000 acres and handles 25 percent of the sewage from 2.5 million people. It has been in operation since 1893.

In spite of the long history of waste disposal on land, research has not fully defined the limitations and potential hazards associated with the practice. The application of wastewater to the land

as an alternative to more conventional methods of wastewater managment has become an emotionally charged and controversial topic in the U.S.A. (10). An author noted that: In the short span of four years, the practice of land disposal has been raised from near extinction to a position of natural eminence (2).

The primary function of land is the production of food and feed for humans and livestock but as the earth's population continues to increase, more and more people urge that land be used for the disposal of their wastes. If we accept the opinion that the expansion of agriculture into new lands has just about ended, then man's management of land already developed is crucial. It is a prime requisite of any disposal system that a waste from one medium be prevented from causing pollution elsewhere. If we propose to use land as a receptor of wastes, then our ultimate objective must be to utilize or dispose of wastes on soils in such a mannner that the practice does not impair the quality or quantity of food produced.

SOIL PROPERTIES AND WASTE DEGRADATION

Soils possess an inherent capacity to provide a medium for the oxidation, reduction, fixation and release of compounds from applied wastes. There are many properties and processes in a soil that determine the feasibility of using land as a waste disposal medium.

Soil Aeration and Drainage

The kind and extent of microbial degradation of wastes containing organic materials and the subsequent release of by-products are determined in part, by soil aeration and the oxygen status. Soils that are naturally well-drained provide an aerobic environment for waste decomposition. In the presence of free oxygen, many carbonaceous compounds are oxidized to simpler and more stable states and simultaneously produce energy.

The utilization of sludge on agricultural soils involves the fate of many elements and compounds. Of particular interest is the fate of the nitrogenous compounds. Under appropriate conditions, notably an aerobic environment, many organic nitrogenous materials are transformed

to ammonium-nitrogen or nitrate-nitrogen. The nitrate ion is mobile and moves freely with the soil solution; the ammonium ion may become part of the soil cation exchange complex and subsequently oxidized to the nitrate form or absorbed by plants. Similarly, the oxygen status of a soil determines the level of oxidation of several metallic elements, such as iron, manganese.

Under temporary or sustained anaerobic conditions in a soil, the initial and intermediate products of decomposition are unoxidized. Many products from the anaerobic degradation of sludges are characteristically foul-smelling and may inhibit plant growth. The incomplete oxidation of nitrogenous compounds results in an accumulation of ammonium nitrogen in the soil profile or in the percolating waters. When oxygen becomes limiting and an energy source is available, significant losses of nitrogen occur by denitrification. These biological processes effectively reduce nitrogen in the nitrate form to gaseous nitrogen. Considerable research is required to adequately determine the magnitude of the losses by denitrification and eventually, in some situations, use the process advantageously.

Various studies have demonstrated that under aerobic soil conditions phosphorus is rendered immobile by fixation or precipitation; but, if the system is place under anaerobic conditions, the phosphorus is released as a mobile compound. This reversal of mobility has special implications in terms of sludge utilization on soils, if anaerobic conditions exist.

Normally, soils with a high watertable and presumably an anaerobic environment are not suitable media for waste disposal or utilization from the hydrological or nutrient removal standpoint.

CURRENT RESEARCH

At the Elora Research Station, anaerobically digested sludge has been added for two consecutive years to field plots planted to corn. The soil is normally a well-drained Harriston loam with a surface pH of 7.8 increasing to 8.1 at the 90-cm depth. In addition to recording crop yields, the project provided an opportunity to study the movement and concentrations of nitrogenous compounds in the soil at various times

during the year. Reference will be made to the distribution of phosphorus in the profile and a preliminary assessment of the cadmium in the soil and the corn crop.

Four rates of application were used: 0, 1.25, 2.50, and 5.0 cm of liquid sludge. The amounts of nitrogen, phosphorus and cadmium that were added by these treatments for the two years are shown in Table 1.

NITROGEN

Of the total nitrogen applied in the sludge in 1972, 3 to 12 percent was actually removed by the crop of corn (9). Other nitrogen sinks include ammonia volatilization and denitrification for which no estimates of losses were available. Up to 30 percent of the total nitrogen in the sludge remained in the soil or on the surface as residual solids (9). Laboratory studies indicated that because of the stability of the nitrogen in the residual solids there would be an insignificant addition of nitrate-nitrogen in subsequent cropping seasons from these residuals.

The anaerobically digested sludge contained approximately 0.3 percent total nitrogen (on wet sludge basis). Of this amount about 30 percent of the nitrogen was in readily oxidizable forms, soluble plus exchangeable ammonium, (NH_4^+-N) Table 1. Nitrification of the NH_4^+-N in the applied sludge was underway six days after application but was confined to the upper 30 cm of soil, Figure 1(a). On Sept. 19, there were no significant differences between the nitrate concentrations in the check plots and the 1.25-cm rate, Figure 1(b). However, the concentrations of nitrates under the 2.50 and 5.0-cm rates increased significantly at depths up to 30 cm. Plant uptake of the soluble nitrogen was possibly declining at this time in the growing season. The tendency for the nitrates in the 0 to 30-cm zone to move deeper into the profile (>30cm) was not evident because the soil moisture content was generally lower than the field capacity value. After corn harvest, October 17, precipitation raised the soil moisture above field capacity and contributed to the movement of the nitrated deeper into the profile, Figure 1(c).

Table 1: Quantities of nitrogen, phosphorus and cadmium added in anaerobic sludge over a two-year period.

Element	Treatments, cm. of sludge			
	0.0	1.25	2.50	5.00
	Element added, kg/ha			
Nitrogen				
Kjeldhal N	0.0	760	1530	3060
NH_4^+-N, soluble	0.0	200	410	820
NH_4^+-N, exchangeable	0.0	40	80	160
Phosphorus, total	0.0	550	1100	2200
Cadmium, total	0.0	3.5	7.0	14.0
Solids, total	0.0	1430	2860	5720

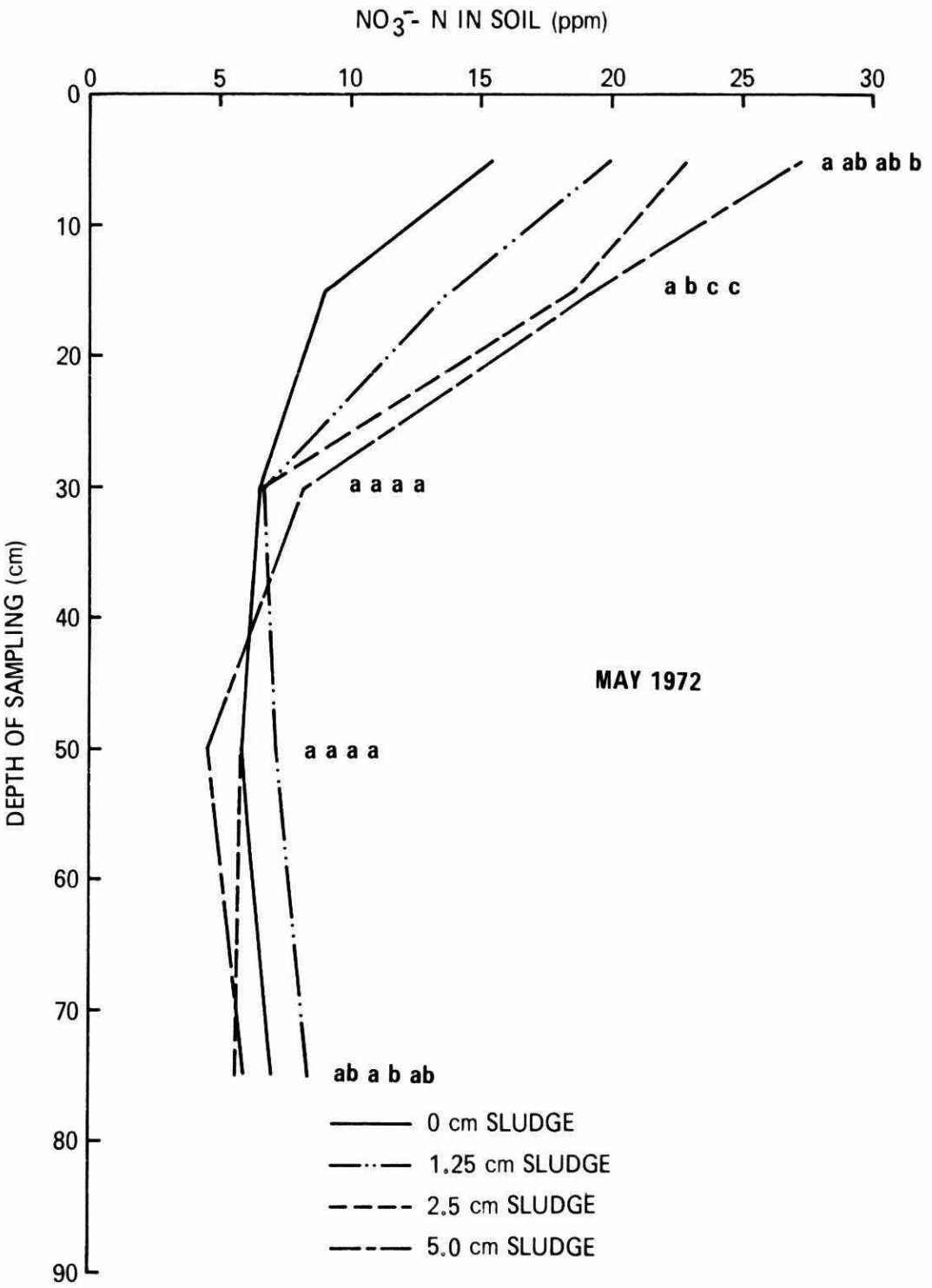

Figure 1a

Variations of NO_3^-- N in soil with depth for various sludge treatments

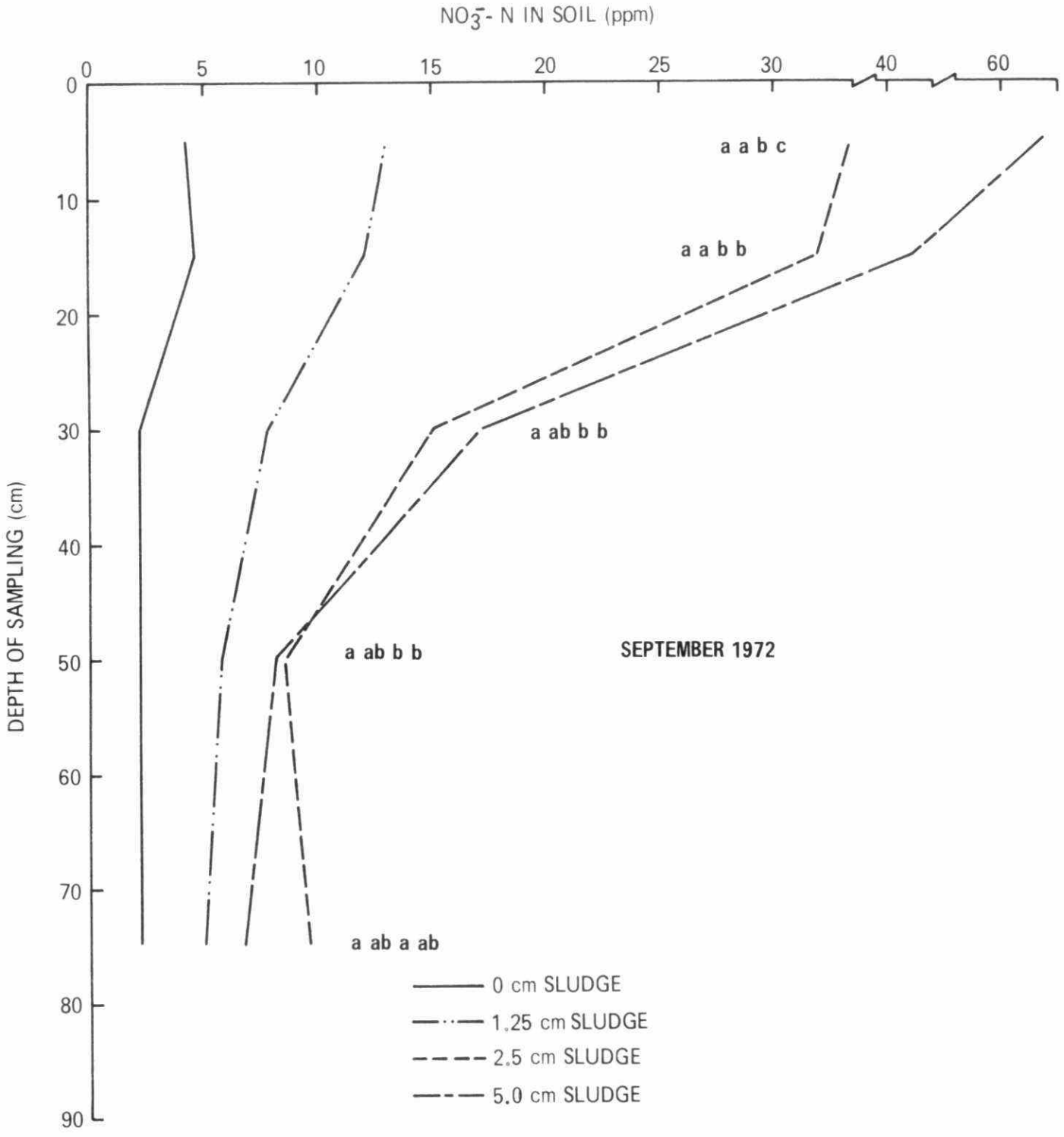

Figure 1b

Variations of NO_3^-- N in soil with depth for various sludge treatments

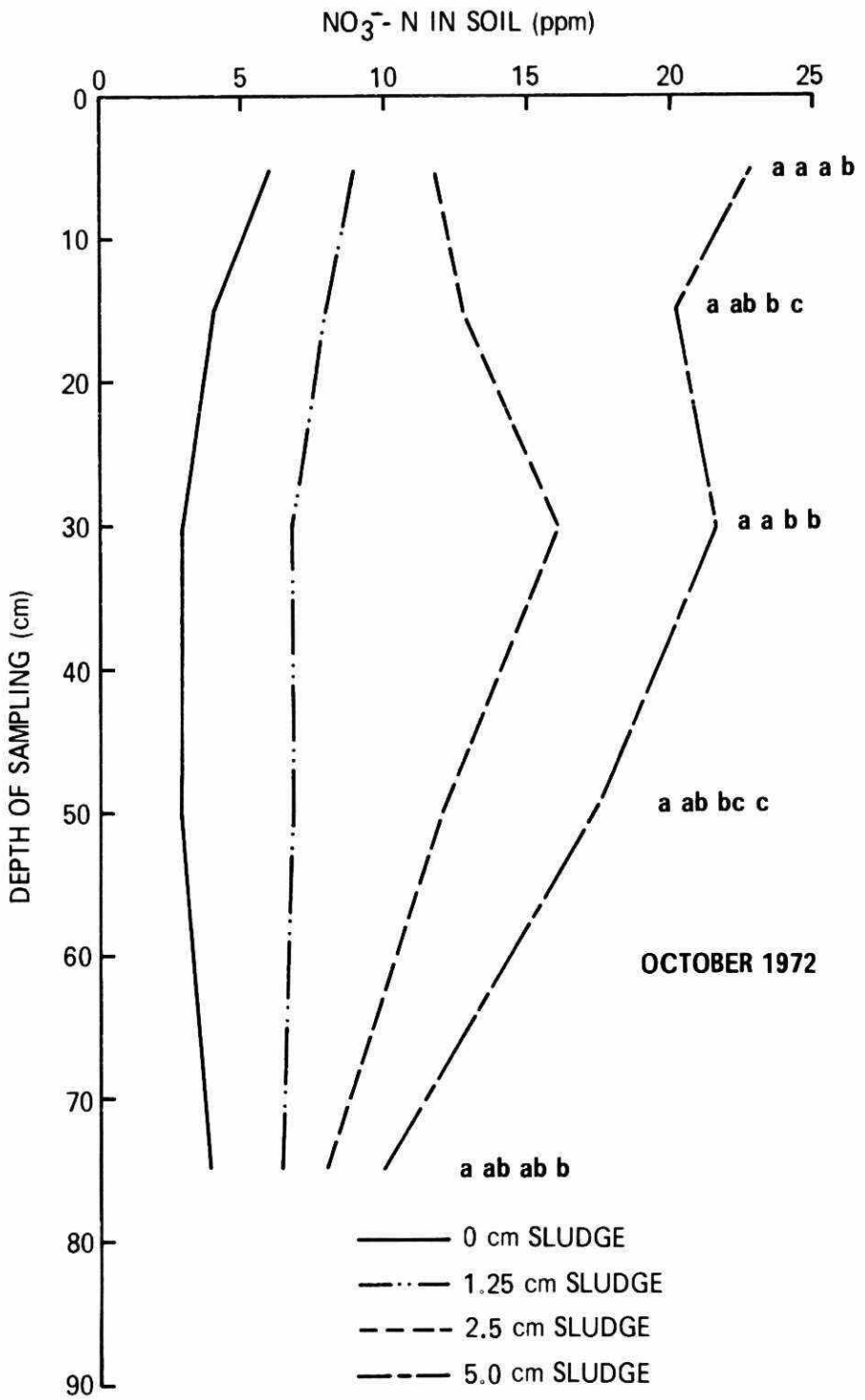

Figure 1c

Variations of NO_3^-- N in soil with depth for various sludge treatments

It is assumed that during late fall, winter and early spring, the nitrate concentrations in the soil profile decreased to values less than those found in October, Figure 1(c). However, it cannot be assumed that all the nitrogen removed from the profile accumulated in the groundwater. There is ample evidence to show that denitrification occurs when nitrates, energy, organisms, a suitable temperature and zero or low oxygen tensions exist (6,7). Figure 1(d) illustrates the concentrations of nitrate-nitrogen in the soil profile at the time of the first sampling in May, 1973. Apparently, nitrification was in progress and would account for the concentrations of nitrate that were found. The lack of significant differences in nitrate-nitrogen concentrations in the 0 to 10-cm depth and the apparent build-up in the 10 to 20-cm layer may be attributed to 3.8 cm of rainfall during the preceeding nine days.

The quantities of nitrate-nitrogen, kg/ha, in the profiles for the four treatments in October 1972 and May 1973 are given in Table 2.

In October 1972, approximately 47, 110 and 180 kg nitrate-nitrogen per ha due to sludge treatment remained in the profile under the 1.25, 2.50 and 5.0 cm treatments respectively. These quantities represented 11 to 13 percent of the total nitrogen added in the sludge treatment. By May, 1973, the corresponding values of nitrate-nitrogen in the profiles were 26, 44 and 93 kg/ha. Presumably, the additional nitrogen in the treated plots over the check plot was due to the previous sludge treatments.

PHOSPHORUS

So much has been written and said about phosphorus in our environment that one hesitates to add to the verbiage. However, the field experiment did provide the opportunity to: (a) establish a relationship between total phosphorus added in the sludge and the amount believed to be plant available, and (b) record the movement and distribution of plant-available phosphorus with depth in the soil profile.

About one percent of the total phosphorus in the anaerobic sludge was found to be in a soluble form. Presumably, the majority of the phosphorus is associated with organics and metals in the sludge.

Table 2: Nitrate-nitrogen content of soil profile (kg/ha) for two periods Oct. 1972 and May 1973 for four sludge treatments.

Sludge treatment	Oct. 1972	May 1973
cm.	NO_3^-N, kg/ha	
0.0	50	65
1.25	97	91
2.50	160	109
5.0	230	158

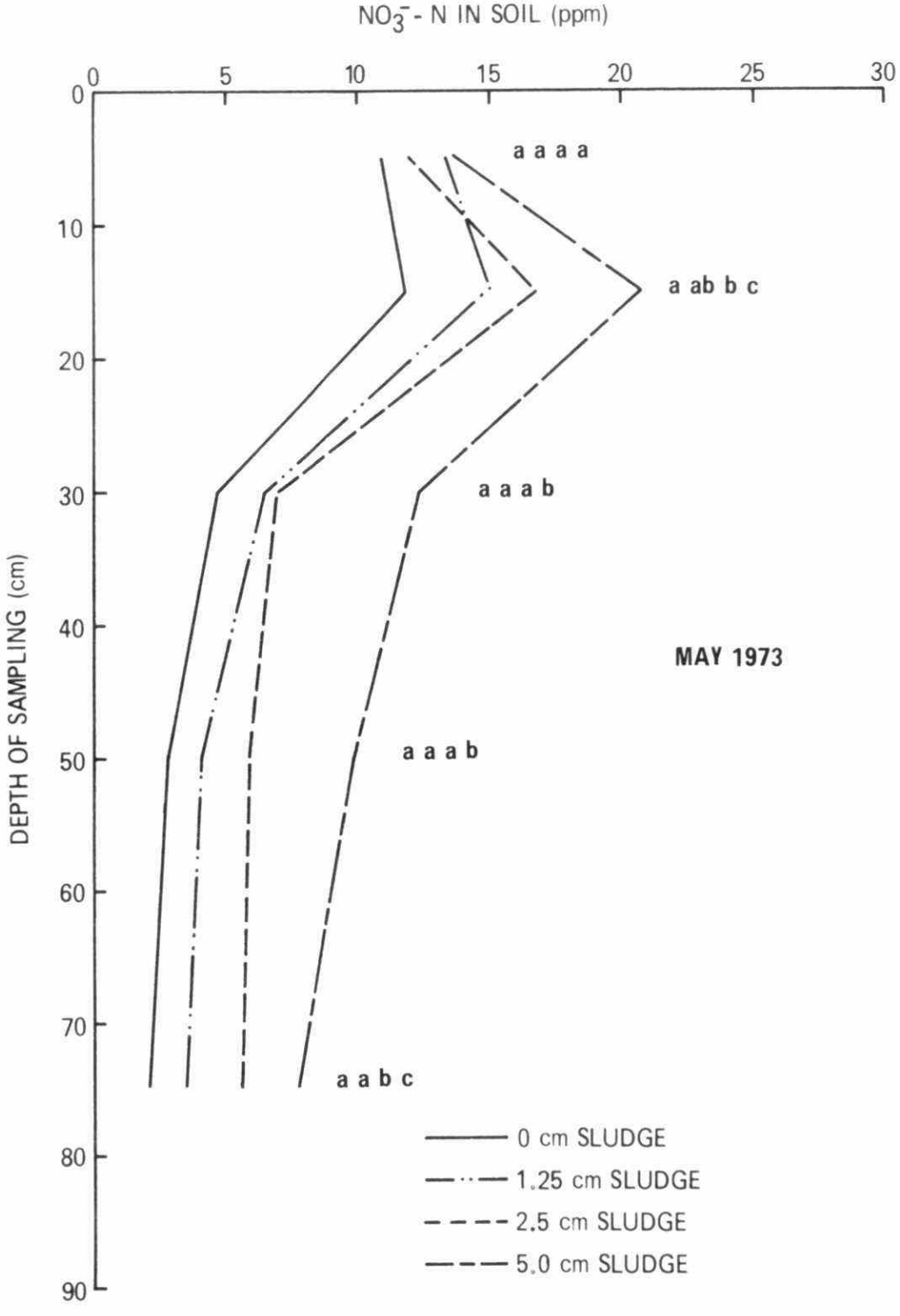

Figure 1d

Variations of NO_3^- - N in soil with depth for various sludge treatments

As the soluble phosphates make contact with the soil calcium, it has been reported that a relatively insoluble hydroxyapatite is formed. Various mechanisms and processes have been proposed to account for the uptake of phosphorus from forms of low solubility by plants.

Plant available phosphorus is described as that phosphorus extracted from soil by a 0.05N sodium bicarbonate solution.* The total phosphorus added in the sludge for the various treatments is recorded in Table 1. The depth of incorporation was approximately 20 cm. The concentration of plant available phosphorus with depth for the various treatments is shown in Figure 2.

It has been demonstrated many times when phosphorus fertilizing materials are incorporated with well-drained surface soils, the element is virtually immobilized. A similar situation was found for the plant-available phosphorus, Figure 2; the greatest concentrations of phosphorus were found in the 0 to 20-cm depth. There was no apparent reason for the significant differences in concentration in the 60 to 90-cm depth in view of the lack of significance in the layer immediately above.

When the soil test value for phosphorus is greater that 20 ppm the general recommendation is that a phosphate fertilizer is not required for corn. These data suggest that up to 1100 kg phosphorus per hectare were required to raise the soil test values above 20 when the phosphorus source was digested sludge.

CADMIUM

While there has been a long history of using sludge on agricultural land, the research has been primarily concerned with the fertilizing value of the waste in crop production. One of the potential hazards associated with the long-term use of urban sludges on land is the accumulation of toxic elements.

Cadmium in the environment presents a health hazard to humans and animals. In Ontario, the maximum allowable concentration of cadmium in drinking water is 0.01 mg/l; zero content is preferred. Published data (8) show that certain crops accumulate excessive amounts of cadmium from cadmium-fortified substrates. The leaf portion of some plants

* The authors express their appreciation to the personnel in the Soil Testing Services, Land Resource Science, University of Guelph for performing these analyses.

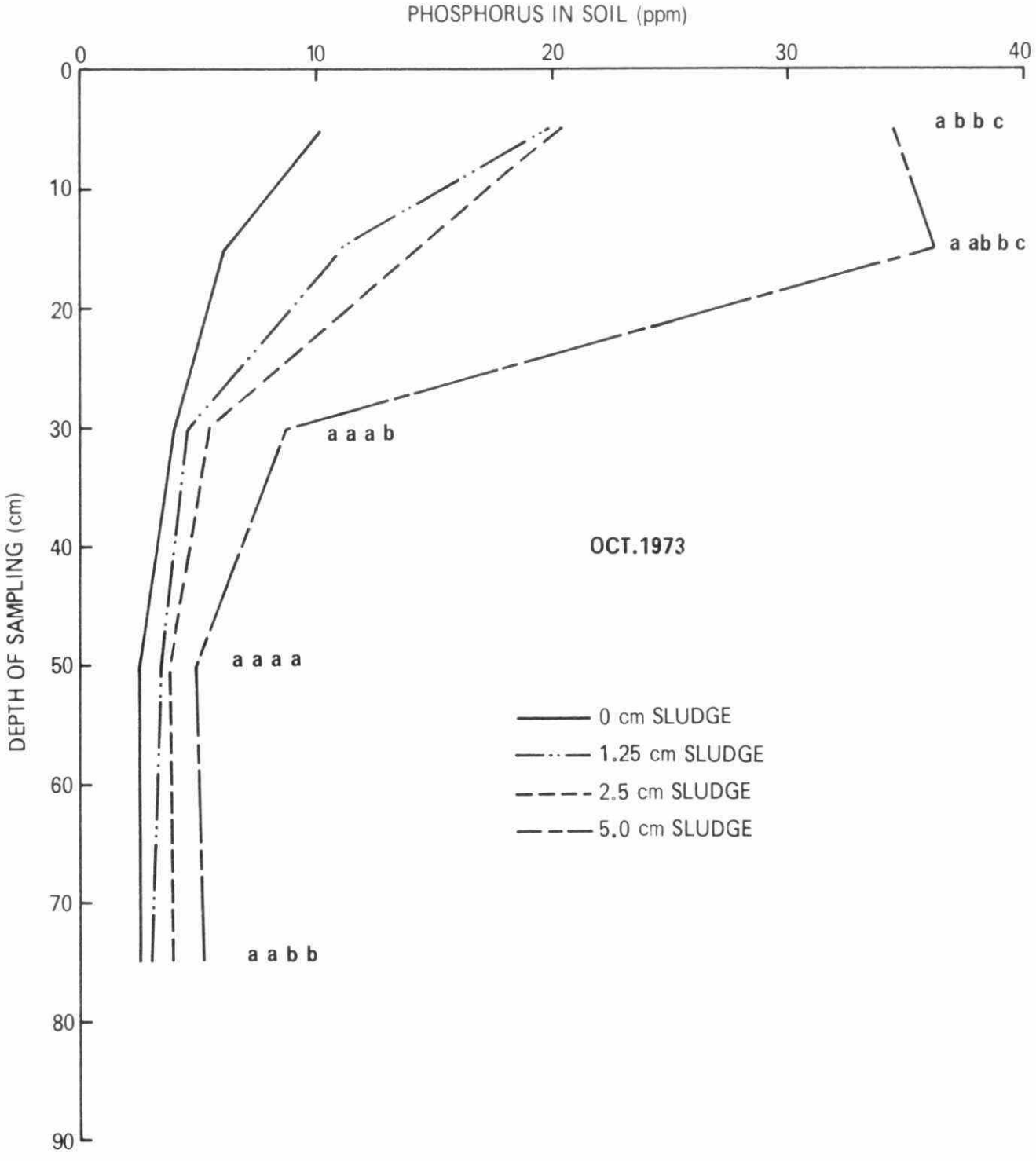

Figure 2

Variations of phosphorus in soil with depth for four rates of suldge application

accumulate substantial amounts of cadmium from sewage-treated soils. As yet, regulatory agencies have not set levels for maximum dietary intake of cadmium by humans.

There is a paucity of data concerning the cadmium content of corn grown on sludge-amended soils. However, Chicago sludge has been applied to a Blount silt loam for three consecutive years (4). The cadmium concentrations in corn leaves at tasseling and in the corn grain at harvest for four treatments are summarized in Table 3.

The Blount silt loam is a poorly drained soil and after a two-year period soil pH decreased from 5.6 to 4.9. Since trace elements would be most mobile or available to plants in poorly drained, acid soils, the concentrations of trace elements in corn tissue samples are higher than would be expected where internal soil drainage is better and soil pH is maintained at a value of 6 or greater. These corn plants did not accumulate toxic levels of trace elements, even under soil conditions which should favor such detrimental conditions to the plant (4).

Our brief summary that forms part of this paper, involves the concentrations of cadmium in soils and corn plants after two applications of anaerobically digested sludge.

Methodology

Cadmium concentrations in sludge, soil and corn were determined using a Techtron AA3 atomic absorption unit. Multi-element standards in 5% nitric acid were used. Sludge was oven-dried and ground to a powder. The powder was digested with H_2SO_4-H_2O_2 and the digest brought to volume with water and analyzed (11). Soil was air-dried, passed through a 2mm stainless steel sieve and ground to about 100 mesh in an agate mortar. The soil was digested using a modified method of Hamm and Stewart (3). The soil was initially allowed to stand overnight in nitric acid and then heated at 60° for thirty minutes. Following this treatment, the soil was digested for one hour in aqua regia. Upon cooling the soil and acid extract were filtered and the filtrate collected. The digestion flask and soil residue were repeatedly rinsed with small portions of 5% nitric acid. The digestion extract and the acid rinsings were collected, brought to volume, and analyzed. Corn grain and stover

Table 3: Amount of cadmium applied to soil and content in corn leaves and grain after three years of sludge applications (4).

Amount applied		Concentration, ug/g	
kg/ha		Leaves	Grain
0		3.3	0.3
27		3.0	0.6
54		5.3	0.8
108		11.6	1.0
	L.S.D.	6.1	0.20

were ground to 20-mesh size in a stainless steel mill. The plant material was ashed in fused silica crucibles at 450° C to black (corn grain) or grey (corn stover) powder. The ash was digested at 70° C in qual regia for one hour. The acid extract was brought to volume with 5% nitric acid, shaken, filtered and analyzed. (Van Loon, Unpublished, 1973).

Cadmium in Soil

It has been postulated that cadmium in a neutral or alkaline environment forms highly insoluble compounds or is strongly adsorbed on organic matter. Figure 3 illustrates the distribution of soil cadmium with depth, after two applications of sludge. The pattern of distribution in the profile is similar to the plot of plant-available phosphorus, Figure 2, except that significant differences in cadmium concentrations due to sludge treatments were not found at the deepest soil layer. When the concentrations in each sampling depth were converted to kg Cd/ha and accumulated for the entire profile, there were 2.9, 5.5, 6.1 and 12.2 kg Cd/ha for the 0.0, 1.25, and 5.0 cm sludge applications respectively.

Cadmium in Plants

The uptake of cadmium by the corn plant (stover and grain) versus the cadmium applied in the sludge is summarized in Table 4. These data indicate that cadmium concentrations in stover and grain increase with increments of applied sludge. For both years, the cadmium content of the stover was greater than the content of the grain. The actual removal of cadmium by a crop of corn (stover plus grain) is negligible and ranges from 1.1×10^{-3} to 1.0×10^{-2} kg Cd/ha.

The linear correlation coefficients (2 degrees of freedom) among cadmium concentrations in grain, stover and at various depths in the soil are summarized in Table 5. These preliminary statistical analyses indicate that cadmium in the grain correlates with cadmium in all soil depths while the concentration in the stover correlates with the cadmium in the 0 to 10 cm depth as well as with cadmium applied. It is planned to investigate further an apparent curvilinear relationship between cadmium in the stover versus cadmium in the soil.

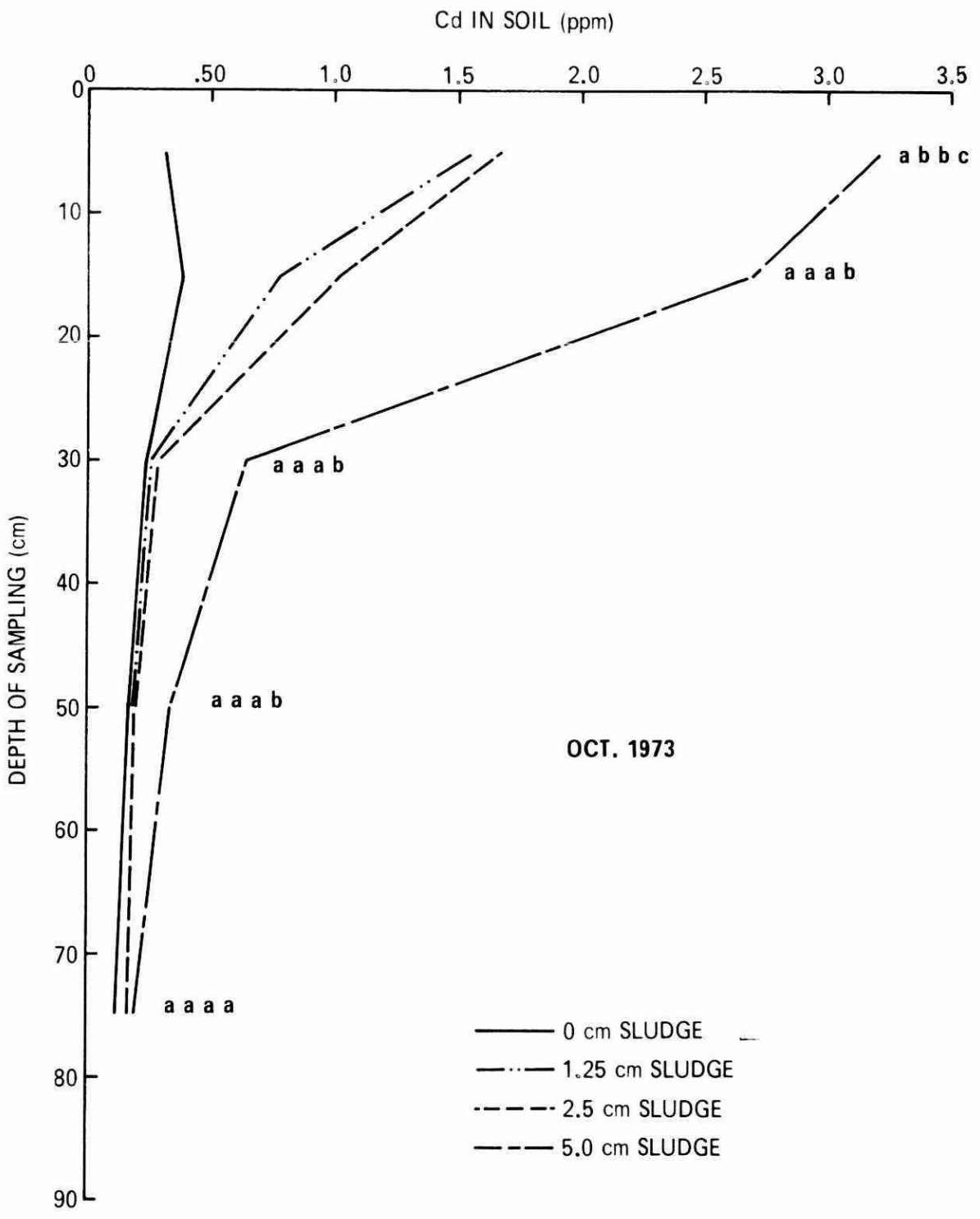

Figure 3

Concentration of cadmium in soil with depth for four rates of sludge application

Table 4: Concentrations of cadmium in corn stover and grain after one and two applications of sludge.

Cd added kg/ha	Concentration, ug/g Stover	Grain
1972		
0.0	0.17 a	0.02 a
1.9	0.47 a	0.04 b
3.8	1.08 b	0.05 b
7.6	1.49 b	0.07 c
1972 plus 1973		
0.0	0.17 a	0.01 a
3.5	0.84 b	0.04 b
7.0	1.24 c	0.06 b
14.0	1.68 d	0.12 c

Means followed by same letter in a given year are not significantly different at 5% level of probability.

Table 5: Linear Correlation coefficients among cadmium concentrations in grain and stover versus cadmium in various soil depths after two applications of sludge.

Variables	R^2
A. Cd concentration in grain vs. Cd concentration in soil	
1. 0 to 10-cm depth	0.970*
2. 10 to 20-cm depth	0.931*
3. 0 to 20-cm depth	0.976*
4. 0 to 90-cm depth	0.957*
5. Cd applied	0.996**
B. Cd concentrations in stover vs. Cd concentration in soil	
1. 0 to 10-cm depth	0.923*
2. 10 to 20-cm depth	0.773 n.s.
3. 0 to 20-cm depth	0.872 n.s.
4. 0 to 90-cm depth	0.826 n.s.
5. Cd applied	0.927*

* significant at 5% level; ** significant at 1% level and n.s. not significant, all based on 2 degrees of freedom.

RESEARCH NEEDS

The use of land as a receptor of sewage sludge has a long history around the world with the primary interest being in the fertilizing value as measured by crop response. It is only within the past decade or so, that scientists have shown an interest in trace elements in the environment and their effects directly or indirectly on humans, animals and plants.

The ultimate sink for nitrogen and phosphorus in urban wastes when incorporated with soil continues to receive high priority in terms of agricultural research and the environment. These two elements are highly suspect in relation to algal growth, lake eutrophication and water quality.

When organic residues decompose in a soil, nitrogen is released as ammonium which in turn is oxidized to nitrites and nitrates. We know a great deal about certain segments of the nitrogen cycle but there are impressive gaps in our knowledge when we attempt to prepare a budget for nitrogen applied and recovered; the unaccountable fraction is charged to denitrification, volatilization, immobilization and other sinks. Of the many chemical relationships in a soil, the carbon to nitrogen ratio could be of major importance when considering the use of soil for waste utilization. A knowledge of and an appreciation for the ratio are basic, if we are to manage and control the application of organic wastes to soils and at the same time use effectively the by-products of the decomposition process (12).

Phosphorus in mineral soils is normally immobilized, being fixed as compounds of calcium, iron and aluminum. As water pollution control facilities in Ontario institute chemical means to precipitate the soluble phosphorus and increase the phosphorus content of sludges, more of the element becomes available for land disposal. There is a potential hazard to water supplies from excessive amounts of soil-applied phosphorus particularly as related to erosion, runoff and the release of soluble phosphorus under anaerobic soil conditions.

Our knowledge gap with respect to trace elements, heavy metals or micro-nutrients appears to be quite broad but much highly relevant

research is planned or underway. We mention just one complex aspect that may eventually affect rates of sludge application, plant uptake and concentration in food and feed for people and livestock. We refer to the protective action of zinc, iron and other elements toward the toxic hazards of cadmium. It has been stated that the concomitant increases of zinc with cadmium would be an advantage in suppressing any toxic hazard that might exist in the ingestion of plant material (soybeans) containing above normal cadmium levels (5). Other researchers suggest that it is not the cadmium concentration in soil, per se, which determines the amount accumulated by plants (8). They note that the zinc-cadmium ratio in the substrate will determine the amounts of cadmium absorbed by plants and as long as this ratio is 200 or greater, foods will not accumulate hazardous concentrations. Chumbley (1) reports that the toxic effects of certain metals to plants are additive. He maintains that it may be permissible to add to an uncontaminated soil a zinc equivalent amounting to 250 ppm of the topsoil over a 30-year period (1). The zinc equivalent is calculated by totalling the zinc concentration plus copper times two and nickel times eight.

The primary function of land is the production of food and feed but if land is to be used for waste assimilation, we must be concerned with the environmental impact. A measure of our progress throughout the next few years will be our ability to manipulate the environment, particularly soil, for the production of food and at the same time as a receptor of wastes.

ACKNOWLEDGEMENTS

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LAND DISPOSAL OF SEWAGE SLUDGE

by

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The objective of this research is to determine maximum rates of sewage sludge application which can be used on agricultural soils without contaminating subsurface water with nitrate nitrogen and surface waters with elements or organisms pathogenic to humans and animals, and without reducing the quality of the crops produced.

1. RUN-OFF

Objectives

To determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year. To ascertain the movement of nutrients and other components of sludge on field plots.

Treatments

Iron precipitated sludge applied at 2 rates (200 and 800 kg N/ha) on a 2.5% slope, and at 1 rate (200 kg N/ha) on a 6% slope as separate treatments in the months of October, January, and April.

Replications - 2
Treatments (including 0 sludge) - 11
Plots - 22
Location - Elora Research Station

Measurements

Run-off sampling will continue through-out the duration of the study. Cropping will be continued using grain corn.

Run-off samples are analyzed for solids, N and P in the total sample and in the water fraction. COD is also determined. The concentration of Cd, Cu, Pb, Ni, Zn and Hg are determined in the total sample and in the fraction.

Soil physical properties will be assessed in relation to differences in run-off which appear. Infiltration rates, and aggregate analyses are to be measured on soil samples. Soil temperatures, frost penetration and snow cover are to be determined on the plots.

2. FIELD RATE AND SOURCE STUDIES

Objective

To provide conditions for the nutrient, metals, bacteriological and soil characterization studies described later in this work statement. (An alternative source of alum sludge will be used during this contract compared to that used last year.)

Corn

Three trials were initiated in 1973 in which the sludge was applied in the Spring and worked in before planting corn. It is intended that the same treatments be applied to the same sites each year.

Sites: Conestogo loam - Elora Research Station

Lisbon loamy sand - Hespeler (Cambridge) Research Station

Oneida clay loam - Farm field near Milton

Treatments

Nitrogen source - ammonium nitrate
- sludge from lime treated sewage
- sludge from aluminum sulfate treated sewage
- sludge from ferric chloride treated sewage

Nitrogen rates from sludge - 200 kg N/ha each year
400 kg N/ha each year
800 kg N/ha each year
1600 kg N/ha each year

Nitrogen rates from ammonium nitrate - 0 kg N/ha each year
100 kg N/ha each year
200 kg N/ha each year
400 kg N/ha each year

4 N sources x 4 rates x 3 replications - 48 plots/site

plot size - 15' x 25'

Grass

In 1973 the chemically treated sludges were applied to a series of plots at the Elora Research Station and this trial will be continued. Sludge will be applied late April, Mid June and in late July. The total annual applications of sludge are the same as those outlined for the corn trials.

3. NUTRIENTS AND HEAVY METALS

Objectives

To determine the rates of the three chemically treated sludges which may be used on typical Ontario soils without harmfully affecting nutrient and heavy metal content of the crop and soil and without contaminating subsurface water with nitrate nitrogen.

Measurements - Corn Trials

N, P, K, Ca and Mg are to be measured on seedling samples. These samples are to be saved for further analysis if required. N, P, K, Ca, Mg, Mn, Zn, Cu, B, Fe, Al, Cd, Pb, Ni, Cr, and Hg to be determined on grain and stover from each plot.

Nitrate N measured on stover from each plot.

Soil pH, P, K and Mg will be monitored in plow depth of each plot each year.

Water samplers are to be installed at the three foot depth under selected plots at the Elora corn site. Water samples are to be obtained in the fall after the crop has been removed, if there is water movement through the profile. The water is to be analyzed for Zn, Cu, Cd, Pb, Ni, and Hg to determine whether sludges cause contamination of groundwater with these elements.

Measurements - Grass Trial

N, P, K, Ca, Mg, Mn, Zn, Cu, B, Cd, Pb, Fe, Al, Ni, Cr, Hg and nitrate N are to be measured in all three cuts of forage.

4. NITROGEN STUDIES

General Objectives

1. To determine the availability to plants of N in chemically

treated sludges.

2. To estimate the losses of N to the groundwaters.

Soil Nitrate and Ammonium in the Field

Objective: To determine the production and movements of NO_3 ions on selected sludge treated plots in relation to soil texture and kind of crop (grass vs corn).

Soil pH, 5 H_2O, exchangeable NH_4^+ and NO_3^- determinations are to be made on the following treatments for the Fe treated sludge:

Corn Plots	Grass Plots
Check	Check
400 kg N/ha	400 kg N/ha
800 kg N/ha	800 kg N/ha

a) Mid-September (when the corn crop has stopped growing).

b) Late November (before freeze-up to determine changes in NO_3^- in soil layers from Mid-September).

Samples were also collected in early Spring and late June.

In addition to the Fe sludge plots listed above, plots receiving the 400 and 800 kg N/ha treatments of the Ca and Al sludge along with the NH_4NO_3 plots receiving 100 and 400 kg N/ha are to be sampled.

Subsoil Solution Studies

Objective: To monitor the concentration of NO_3^- in the subsoil solution before freeze-up in the Fall and after thawing in the Spring.

Where soil moisture is adequate NO_3^- and Cl^- levels in the subsurface soil solution at a selected depth are to be monitored weekly in the Fall of 1974 and Spring of 1975, and occasionally during the Winter months if the weather permits. The data obtained are to be used to augment the information obtained with the soil sampling with depth.

The soil solution samplers are to be placed in the 200, 400 and 800 kg N/ha plots where Fe sludge has been applied as well as the 100 and 400 kg N/ha plots where NH_4NO_3 fertilizer was applied on the corn plots at the Elora Research Station. Soil solution samplers are also to be put in the check and 800 kg N/ha (Spring applied sludge) plots in the run-off experiments.

Laboratory Nitrification Studies

Objective: To determine the relative rates of transformation of ammonium to nitrate (nitrification) and organic N to ammonium (mineralization) in soil treated with different chemically treated sludges.

This part of the study will augment the field study inasmuch as it will permit better comparisons of the transformations of N of different sludges incubated with soil.

5. MICROBIOLOGICAL EXAMINATION

Objectives

1. To determine the numbers of total coliforms, faecal coliforms and faecal streptrococci present in the applied sludges.
2. To determine the presence or absence of members of the genera Salmonella and Shigella or closely related groups of enteric bacteria in the applied sludge.
3. To select isolates of the coliforms, faecal coliforms, faecal streptrococci Salmonella, Shigella and closely related enteric bacteria for identification and for possible future use in survival studies.
4. To determine the concentration of the various groups of enteric bacteria in run-off waters from check plots and high rate application plots only.
5. To determine the presence or absence of members of the genus Salmonella and Shigella on corn and grass plants grown on: (i) check plots (no sludge) and (ii) high rate application plots.
6. (a) To estimate the length of time a variety of bacteria suspended in sludge will remain viable on the surface of corn plants.
   (b) To estimate the survival time of a variety of bacteria suspended in sludge-soil-water mixtures at several storage temperatures.

6. GREENHOUSE STUDIES

Objectives

1. To establish a simple chemical test for plant available metals in soils by selecting suitable extractants with particular emphasis on copper and cadmium.

2. To determine the affect of metals in sewage sludge on metal uptake by plants.
3. To determine the availability of nitrogen in sewage sludges.
4. To determine the affect of various sewage sludges on crop growth.

Plan of Research - Experiment I

Sludge application is to continue at 2 pH values using 9 sludges at three application rates (200, 800 and 1,600 kg N/ha) with two checks.

Rye grass yields will be taken and plants samples analyzed for N, P, K, Ca, Mg, Fe, Al, Mn, Zn, Cu, B, Cd, Hg, Pb, Ni and Cr and total solids.

Soils from each plot are to be analyzed for NH_4-N and NO_3-N after each crop is harvested. Total nitrogen is to be determined at the end of the experiment.

Reseeding, harvesting and analysis are to continue until three crops have been harvested.

Plan of Research - Experiment II

In experiment II a group of soils are to be extracted with various chemicals as measures of available metal content. The amounts of metals extracted are to be compared with those taken up by a crop of annual rye grass grown on these soils.

7. SOIL CHARACTERIZATION

Characterization of soils from the field grass experiment.

Reasons for the Research

As the sludge has been added to the grass field plots during this experiment new surface structures have formed. Sludge and elemental precipitates have moved into the soil. The measurement of the extent of movement and nature of the new soil structure at this time could be useful in making an earlier projection on soil capacities to carry sludge.

Objectives

1. To evaluate soil structure produced by sewage sludge applications on field plots.
2. To evaluate extent of movement into the soil of Ca, Fe, Al elements used in sludge treatment.

EFFECTS OF SEWAGE SLUDGE ON CROP GROWTH AND NUTRIENT AND METAL UPTAKE

by

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The objectives and methods used in the various experiments have been described in the two previous papers on the University of Guelph project.

The nutrient and metal contents of the sludges used in greenhouse experiment I are presented in Tables 1 and 2, and the amounts of nutrients and metals supplied when sludge is used at the 200 kg/ha rate are presented in Tables 3 and 4. Sludges used in the field experiments in 1973 were Newmarket (lime), Point Edward (aluminum) and North Toronto (iron). Since these were applied several months earlier than in the greenhouse trials the analyses of the sludges used in the field are not exactly as shown in Table 1 and 4.

Field Experiments

Total yields of bromegrass from the grass experiment as harvested in three consecutive cuttings are presented in Table 5. Yield increased with each increase in rate of ammonium nitrate. None of the sludges yielded as high as the ammonium nitrate treatments, the difference being greatest in the first cut. Sludges were applied later than is desirable and may have delayed growth by covering some of the new shoots at a very critical stage in growth. The Ca and Fe sludges outyielded the Al sludge at all but the lowest rate of application. There is evidence that poor growth iwht the aluminum sludge from Point Edward is not due to aluminum treatment of the sewage.*

Grain and stover yields in the three corn trials did not follow a consistent pattern. At the Elora and Milton sites, there was a response to nitrogen fertilizer and to sludge but on the very

* Personal communication with Dr. D. Liu, Canada Centre for Inland Waters, Burlington, Ontario.

droughty soil at Cambridge there was a decrease in yield due to nitrogen. The aluminum sludge produced as high yields of corn as the other two sludges.

In 1974 there appear to be visible growth responses to all three sewage sludges in the grass experiment and the three corn trials.

Sewage sludge is believed to be a good source of phosphorus for plants but the field experiments do not illustrate this very clearly. There was a tendancy for phosphorus concentration in bromegrass to increase some from the first to the third cut where sludge was applied. This may indicate that sludge phosphorus takes some time to become available.

The sludges used in the field experiments were not particularly high in metals (Tables 1 to 4). However, there was some indication of increased copper concentration due to sludge application in corn stover from two of the trials. Nitrogen additions tended to increase zinc content of the crops and in some cases this was more marked with sludge than with ammonium nitrate. Perhaps the most interesting information from metal analyses of the field crops at this stage is the very small amount of metals removed by the crops in one season (Table 6).

Greenhouse Trials

In regard to metals, greenhouse experiment I is more likely to provide information on toxicities than the field experiments because of the higher metal content of some of the sludges used (Table 1 to 4). One crop of annual ryegrass has been grown on Grimsby sandy loam with the pH adjusted to 5.0 and 7.0 before addition of the sludges. Although these data have not been fully evaluated some other marked effects are apparent.

The Fergus sludge when applied at 800 or 1600 kg N/ha markedly reduced growth of ryegrass at a soil of pH 5 but not at pH 7. This toxicity is believed to be due to copper; the 1600 kg N/ha rate supplying 206 kg Cu/ha. Sludge from Midland did not produce marked effects in growth but when applied at 1600 kg N/ha the ryegrass contained approximately 60 ppm Ni at soil pH of 5.0 and 30 ppm Ni at soil pH of 7.0 compared to 4 or 5 ppm Ni with other treatments. Some of the sludges produced up to

450 ppm zinc in the ryegrass compared to values of 30 ppm Zn where no sludge was applied. These data still need more study and at least two more crops will be grown with and without further additions of sludge. It is obvious at this stage, however, that some sludges do pose a very serious metal problem if applied to land.

TABLE 1. METAL CONCENTRATION IN NINE ONTARIO FLUID SEWAGE SLUDGES USED IN 1974 GREENHOUSE EXPERIMENTS.

Treatment Plant	Al	Fe	Mn	Cd	Cr	Cu	Ni	Pb	Zn
					ppm				
Aurora	1487	122	3.8	0.24	194.00	7.0	2.79	5.8	6.8
Midland	670	689	16.1	0.82	107.00	31.0	325.00	80.4	68.9
Point Edward	200	446	19.5	0.20	0.97	27.0	0.55	34.6	31.9
Sarnia	134	1864	76.9	2.56	2.87	19.0	0.69	86.2	314.5
Guelph	71	750	7.1	7.50	132.00	99.0	3.36	45.0	262.5
Fergus	116	463	10.9	2.66	142.00	277.0	2.96	15.1	537.0
North Toronto	810	5700	27.3	2.49	48.00	93.0	2.10	120.0	225.0
Newmarket	179	450	25.1	0.21	1.30	16.4	0.26	9.4	42.3
Toronto Humber	285	1022	10.6	4.35	95.60	46.7	16.80	7.7	186.9

TABLE 2. CONCENTRATIONS OF VARIOUS CONSTITUENTS IN NINE ONTARIO FLUID SEWAGE SLUDGES USED IN 1974 GREENHOUSE EXPERIMENTS.

Treatment Plant	D.M. %	N %	P %	K ppm	Ca ppm	Mg ppm	Na ppm
Aurora	1.7	0.10	0.08	40	1100	110	161
Midland	3.8	0.11	0.21	38	3150	277	96
Point Edward	3.6	0.15	0.09	46	3250	309	86
Sarnia	2.3	0.13	0.13	49	850	227	50
Guelph	3.0	0.17	0.08	78	1750	300	188
Fergus	3.7	0.22	0.06	82	1850	471	684
North Toronto	6.0	0.30	0.29	120	2200	420	102
Newmarket	5.3	0.10	0.06	71	9900	315	143
Toronto Humber	2.9	0.17	0.08	120	1450	204	153

TABLE 3. AMOUNTS OF VARIOUS CONSTITUENTS SUPPLIED AND AMOUNTS OF ONTARIO SLUDGES CONTAINING 200 kg TOTAL NITROGEN.

Treatment Plant	SOLIDS	P	K	Ca	Mg	Na
				Kg/ha		
Aurora	3501	164	8	231	23	33.90
Midland	7026	386	7	577	51	17.62
Point Edward	5282	124	6	447	43	11.27
Sarnia	3530	197	7	129	34	7.57
Guelph	3529	93	9	206	35	22.12
Fergus	3442	56	8	172	44	63.62
North Toronto	4027	194	8	148	28	6.84
Newmarket	11135	126	15	2084	66	30.10
Toronto Humber	3497	96	14	174	24	18.33

TABLE 4. AMOUNTS OF METALS SUPPLIED BY AMOUNTS OF ONTARIO SLUDGES CONTAINING 200 kg TOTAL NITROGEN.

Treatment Plant	Al	Mn	Fe	Cd	Cr	Cu	Ni	Pb	Zn
					kg/ha				
Aurora	312.0	0.79	25	0.05	40.80	1.47	0.58	1.21	1.43
Midland	122.0	2.96	126	0.15	19.63	5.68	59.62	14.75	12.64
Point Edward	27.5	2.68	61	0.02	0.13	3.72	0.07	4.76	4.40
Sarnia	20.3	11.68	282	0.38	0.43	2.88	0.10	13.10	47.65
Guelph	8.3	0.83	88	0.88	15.50	11.64	0.39	5.29	30.87
Fergus	10.8	1.01	43	0.25	13.21	25.76	0.28	1.40	49.95
North Toronto	54.4	1.83	382	0.17	3.22	6.24	0.15	8.04	15.10
Newmarket	37.6	5.28	94	0.05	0.27	3.45	0.06	1.97	8.91
Toronto Humber	34.2	1.27	122	0.52	11.45	5.60	2.01	0.92	22.70

TABLE 5. ANNUAL DRY MATTER YIELD OF BROMEGRASS FROM THREE CUTTINGS.* ELORA, 1973.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
	dry matter - lb/ac (kg/ha)				
0 (0)	1980 a (2200)				
89 (100)	4480 c (5020)				
178 (200)	5310 de (5950)	2480 a (2780)	2190 a (2460)	2550 a (2860)	2410 (2700)
356 (400)	6360 f (7130)	3650 b (4090)	2560 a (2870)	3800 b (4260)	3340 (3740)
712 (800)		4760 cd (5330)	3350 b (3750)	5200 de (5830)	4440 (5970)
1424 (1600)		5610 e (6290)	3360 b (3760)	5480 de (6140)	4820 (5400)
Average **		4130 (4620)	2870 (3210)	4260 (4770)	3750 (4200)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability.

** Source and rate of sludge and the source-rate interaction are significant effects by "F" test at 0.01 probability.

TABLE 6. REMOVAL OF METALS IN CORN GRAIN AND STOVER. ELORA 1973.

Element	NITROGEN SOURCE AND RATE		
	Ammonium Nitrate		Iron Sludge
	200 kg N/ha	400 kg N/ha	1600 kg N/ha
	Amount Removed by Crop - kg/ha		
N	116	130	120
P	25	27	30
K	65	74	78
Ca	20	21	22
Mg	26	27	27
B	.035	.040	.041
Cd	.0014	.0019	.0023
Cr	.0096	.0059	.0068
Cu	.060	.042	.068
Hg	.0005	.0005	.0006
Mn	.234	.268	.286
Ni	.011	.011	.006
Pb	.036	.035	.034
Zn	.256	.245	.381

NITROGEN TRANSFORMATION AND UPTAKE

by

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Introduction

Nitrogen is one of the limiting factors in the disposal of sewage sludges on agricultural lands. If nitrogen is applied at a rate which exceeds crop requirements there is a danger of polluting ground and surface waters with nitrate. Therefore, it is important to know the forms of nitrogen in sludge and their availability to crops. The purpose of this paper is to illustrate some of the more important transformations of sludge nitrogen and to discuss their importance to crops and the environment.

Characteristics of Sludge Nitrogen

The two most easily identifiable N fractions in sludges are organic N and ammonium (NH_4^+). The total N content of anaerobically digested sludges may vary between 0.1 and 0.3 percent on a fluid basis. The NH_4^+-N content may comprise between 2- and 50 percent of the total N. While such variation may occur amongst sewage treatment plants, considerable variation may also occur with time at any one plant.

Transformation of Sludge N

The important transformations of sludge N are illustrated in Figure 1. It should be obvious from the number and kinds of transformations that it is very difficult to predict the fate of sludge N precisely in quantitative terms. However, some gross measurements in the field as well as in the laboratory may give us some idea of the fate of sludge N. The organic N fraction has generally been considered to be relatively stable to mineralization in soil (1, 4, 6, 8). Some have found that a significant portion of the organic N in sludges may be easily mineralized in soil (2, 9). This aspect requires further research. Ammonium in sludge mixed with soil is readily converted to NO_3^- via the nitrification process (7, 8, 9, 10).

In addition to the conversion of NH_4^+ to NO_3^-, NH_4^+ may be lost

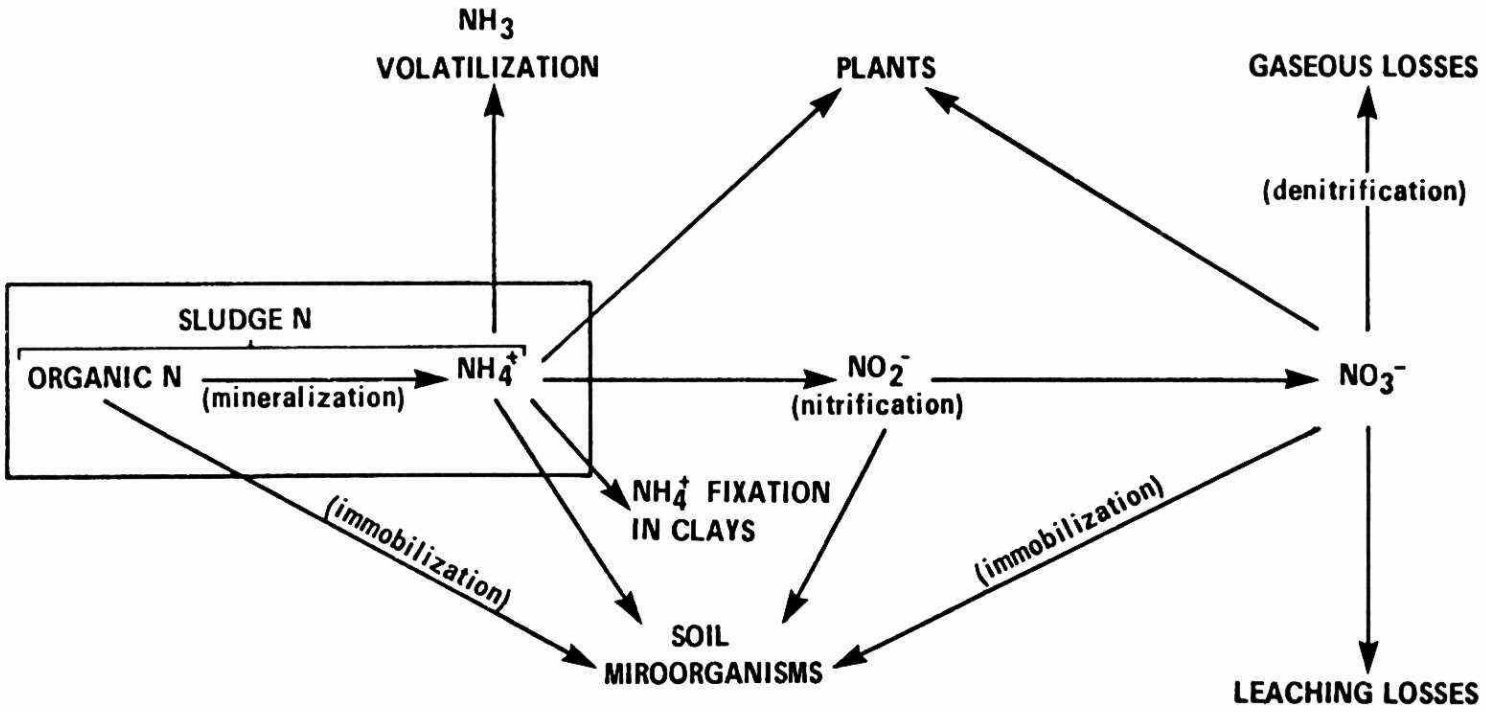

FIGURE 1. N CYCLE ILLUSTRATING THE FATE OF SLUDGE N.

through volatilization of ammonia (NH_3) after application to the soil surface or even after mixing in the soil. Recent research at the University of Guelph suggests that up to three quarters of NH_4^+-N may be lost via the volatilization process depending on soil and environmental conditions. Ammonium may be fixed by clay minerals in the soil although the importance of this process is uncertain. Organic N, NH_4^+, and NO_3^- may be utilized directly by soil microorganisms (immobilization). Eventually, the sludge N remaining in the soil becomes part of the soil N cycle.

Data presented in the following were obtained from laboratory and field studies on chemically treated, anaerobically digested sludges at the University of Guelph. Although the data are limited in scope, they serve to partly illustrate the transformations of sludge N and the consequential importance of this transformation.

From the point of view of crop uptake and ground or surface drainage water pollution, the nitrification process involving the conversion of NH_4^+ to NO_3 is most important. While plants can adsorb both NH_4^+ and NO_3^-, the latter may be lost through leaching and/or denitrification. While it is known that nitrification of sludge NH_4^+ in soil readily occurs, nothing is known about the possible affect chemical treatment of sewage for phosphorus removal would have on sludge N transformation.

A laboratory experiment was conducted whereby sludges resulting from sewage treated with lime (Newmarket), aluminum sulphate (Point Edward) or iron chloride (North Toronto) were each mixed with a soil-sand (1:1) mixture and leached with water following weekly incubation periods at 25°C. Sludge at a rate of 12,250 µg total N per 30g of soil-sand mixture was applied to the surface of the mixture and allowed to dry. Following a 9-day drying period, the dry "pad" was intimately mixed with the soil-sand mixture with a mortar and pestle. The mixture was then leached immediately and thereafter at weekly intervals. The procedure was considered to approximately simulate field application of sludge.

The accumulation of NO_3^- in the leachings over a 27-week period is presented in Figure 2. During the first week, apparently all of the available NH_4^+ was nitrified in the soil treated with Ca- or Fe-sludge. However, the amount of NH_4^+ nitrified did not equal the total amount of NH_4^+-N available from each sludge as shown in Figure 2.

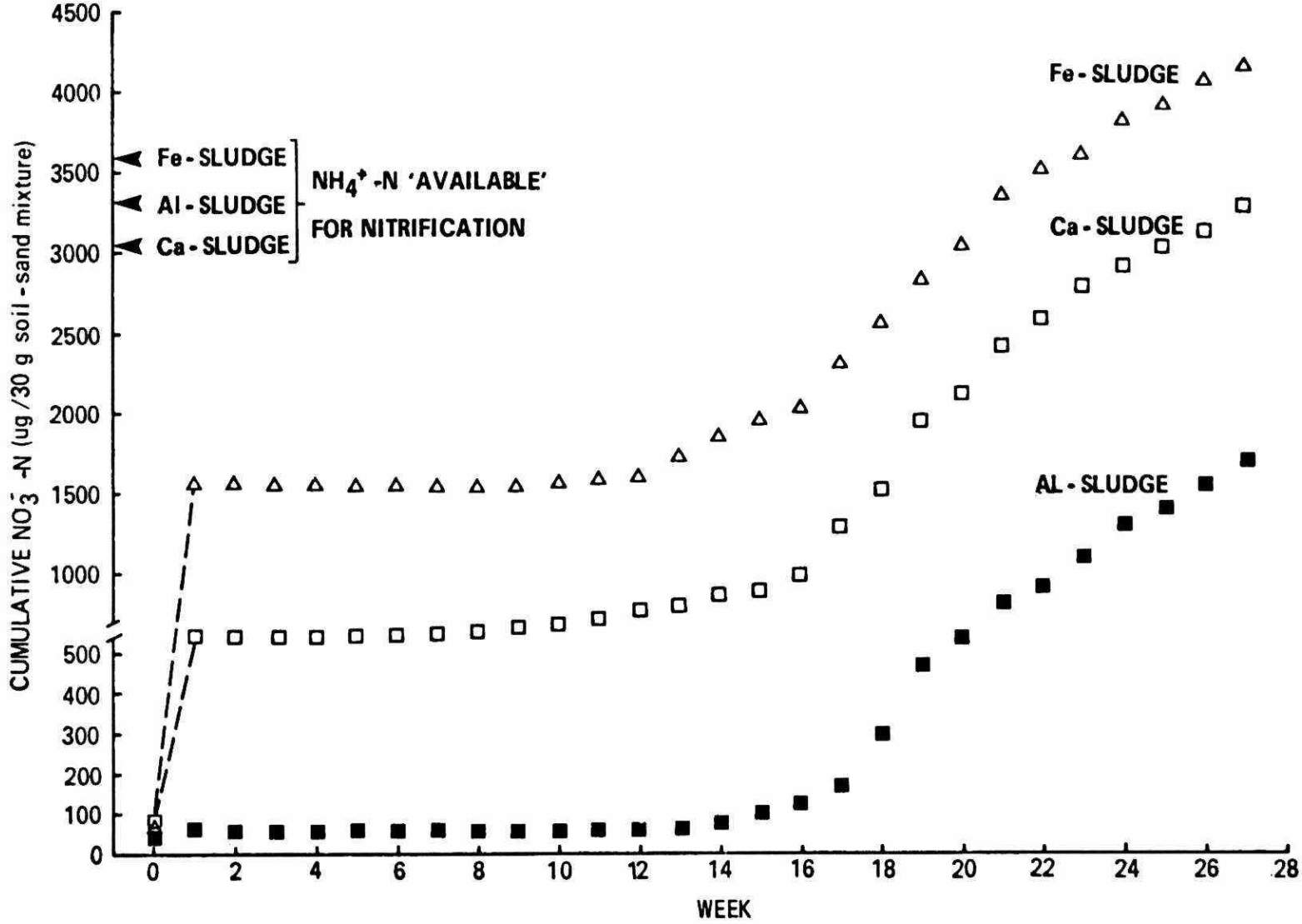

FIGURE 2. CUMULATION OF NO_3^--N IN A 30 GRAM SOIL-SAND MIXTURE TREATED WITH 12,250 µg SLUDGE -N FROM THREE CHEMICALLY TREATED, ANAEROBICALLY DIGESTED SLUDGES.

"Available" NH_4^+-N equalled NH_4^+-N added in the sludge minus the NH_4^+-N leached during the first two weeks. It is suggested that NH_4^+ loss through volatilization of NH_3 plus immobilization by soil microorganisms would account for the relatively small portion of the "available" NH_4^+ which was nitrified. The relatively high rate of sludge application may have resulted in denitrification losses as well (8, 9). In the case of the Al-treated sludge, however, it is known that this sludge contained an abnormally large quantity of hydrocarbons (3) which may have been toxic to microorganisms involved in the nitrification process.

It is particulary noteworthy that ALL of the sludge treatments produced NO_3^- again approximately after 12-16 weeks. It is supposed that this "flush" of NO_3^- originated from the mineralization of organic N in the sludges including the N which was previously immobilized. The apparent toxicity of hydrocarbon substances in the Al-sludge dissipated although the rate of NO_3^- production appeared to be slightly lower than for the other two sludges. The fate of "available" NH_4^+ in the soil treated with Al-sludge at the beginning of the incubation period is unknown, although some NH_4^+ appeared in the first two leachings. The rate of NO_3^- production appeared to begin decreasing from 21 weeks onward for all sludges.

The appearance of NO_3^- after such a long incubation period (12-16 weeks) raises questions about its availability to a crop or leaching loss. It would be expected that, under field conditions, the appearance of this "flush" of NO_3^- would be too late to benefit a crop if sludge were applied during the previous 12 months assuming that mineralization would occur only during the warmer months. Should a second NO_3^- "flush" occur in the fall after the crop growth has ceased, it would increase the possibility of NO_3^- contamination of ground and drainage waters with sludge application. Also, the apparent lag period may be longer in the field because conditions for mineralization would probably not be as favourable as in the laboratory. This could mean a release of NO_3^- during the following spring. No other reported study has involved an incubation period as long as that for this study with the appearance of NO_3^- after a lengthy lag period.

Measurement of NO_3^- in soil profiles in the field have supported the conclusion that NH_4^+ in applied sludge is very rapidly transformed to NO_3^- in the soil. It has been found that all of the NH_4^+ is apparently converted to NO_3^- by late June if sludge is applied and incorporated into the soil in early May before a corn crop is planted (Figures 3, 4 and 5). Some substantial rainfalls during June apparently moved NO_3^- down the profiles by the late June or early July sampling on all three soils. The disappearance of NO_3^- from the profile between June and early October is mainly due to uptake by plants. However, at the rates of sludge shown, a substantial quantity of NO_3^- remained in the profiles when plant uptake ceased. It is noteworthy that movement of NO_3^- occurred during November in the sandy loam soil (Figure 3) and silt loam soil (Figure 4) after a 1.7 cm rainfall over two days in early November. In the clay loam soil, however, NO_3^- movement did not appear to occur (Figure 5). However, the NO_3^- concentration in the profile appeared to decrease between October and November. The disappearance of NO_3^- could be attributed to denitrification in this finer textured soil although this remains to be ascertained.

To supplement the NO_3^--N concentration measurements in the soil profile, ceramic-tipped, soil solution samplers were inserted in selected corn field plots on a silt loam soil to a depth of approximately 65 cm where Fe- sludge was applied at 800 kg total N/ha in the previous fall, winter or spring (before planting) and where 90 kg N/ha was applied as NH_4NO_3. Soil solution samples were obtained periodically beginning in September when the water content of the soil was high enough. The NO_3^--N concentrations increased dramatically in mid-November shortly after more than 3 cm of rain occurred (Figure 6). The relatively high NO_3^--N concentration during late September, October and early November resulting from the winter application are due to unexplainably aberrant levels in one of the four samplers for that treatment. The NO_3^--N concentration in the soil solution during the winter and spring periods was considerably higher than that normally tolerated (10 µg NO_3^--N/ml). On the other hand, the normally fertilized corn plots showed relatively low NO_3^--N concentrations during the whole sampling period.

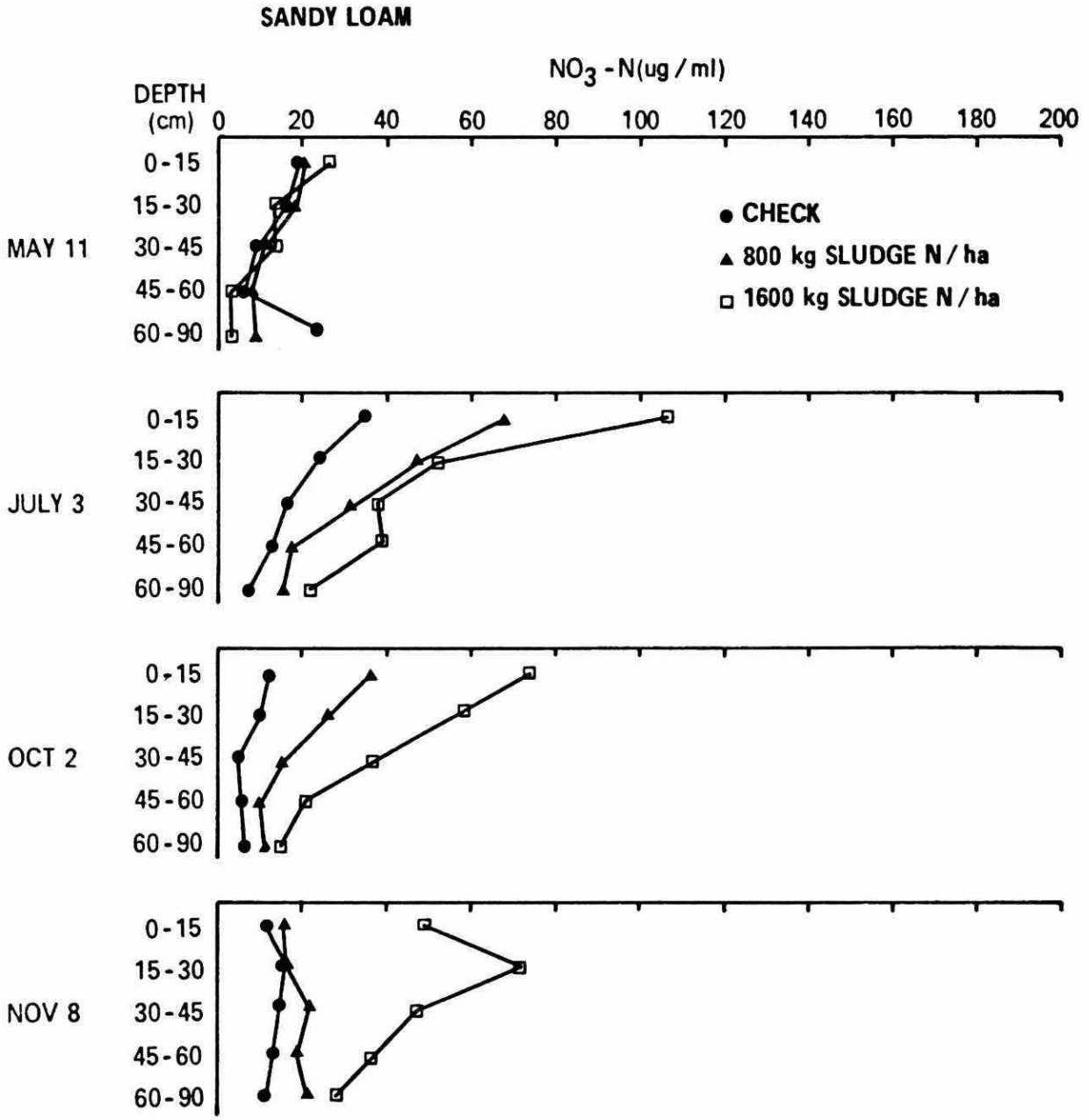

FIGURE 3. CONCENTRATION OF NO_3^--N IN A SANDY LOAM PROFILE TREATED WITH 0 (CHECK), 800, AND 1600 kg SLUDGE N/ha AS FERRIC CHLORIDE-TREATED SLUDGE APPLIED ON MAY 29, 1973.

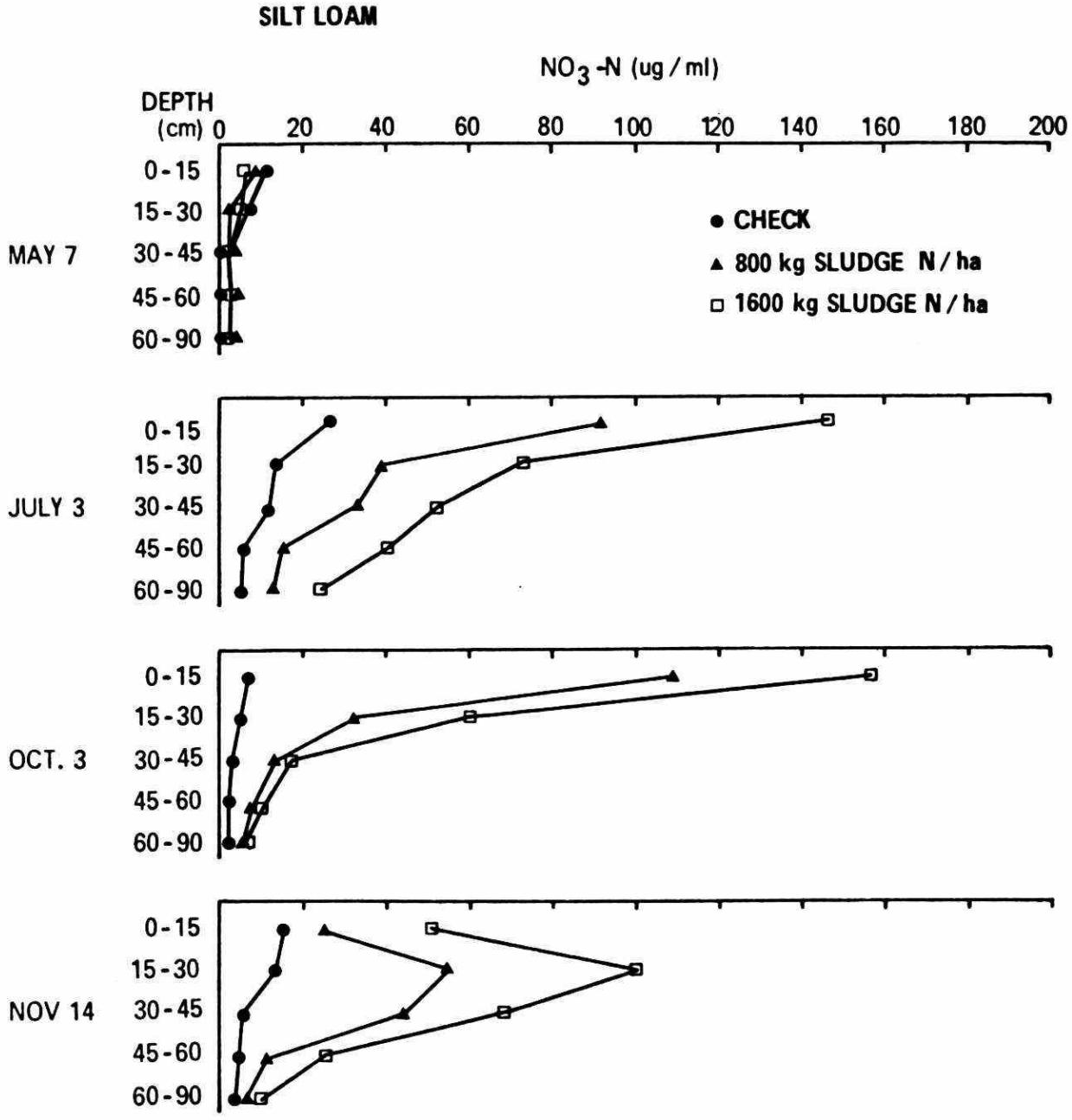

FIGURE 4. CONCENTRATION OF NO_3^--N IN A SILT LOAM PROFILE TREATED WITH 0 (CHECK), 800, AND 1600 kg SLUDGE N/ha AS FERRIC CHLORIDE-TREATED SLUDGE APPLIED ON MAY 10, 1973.

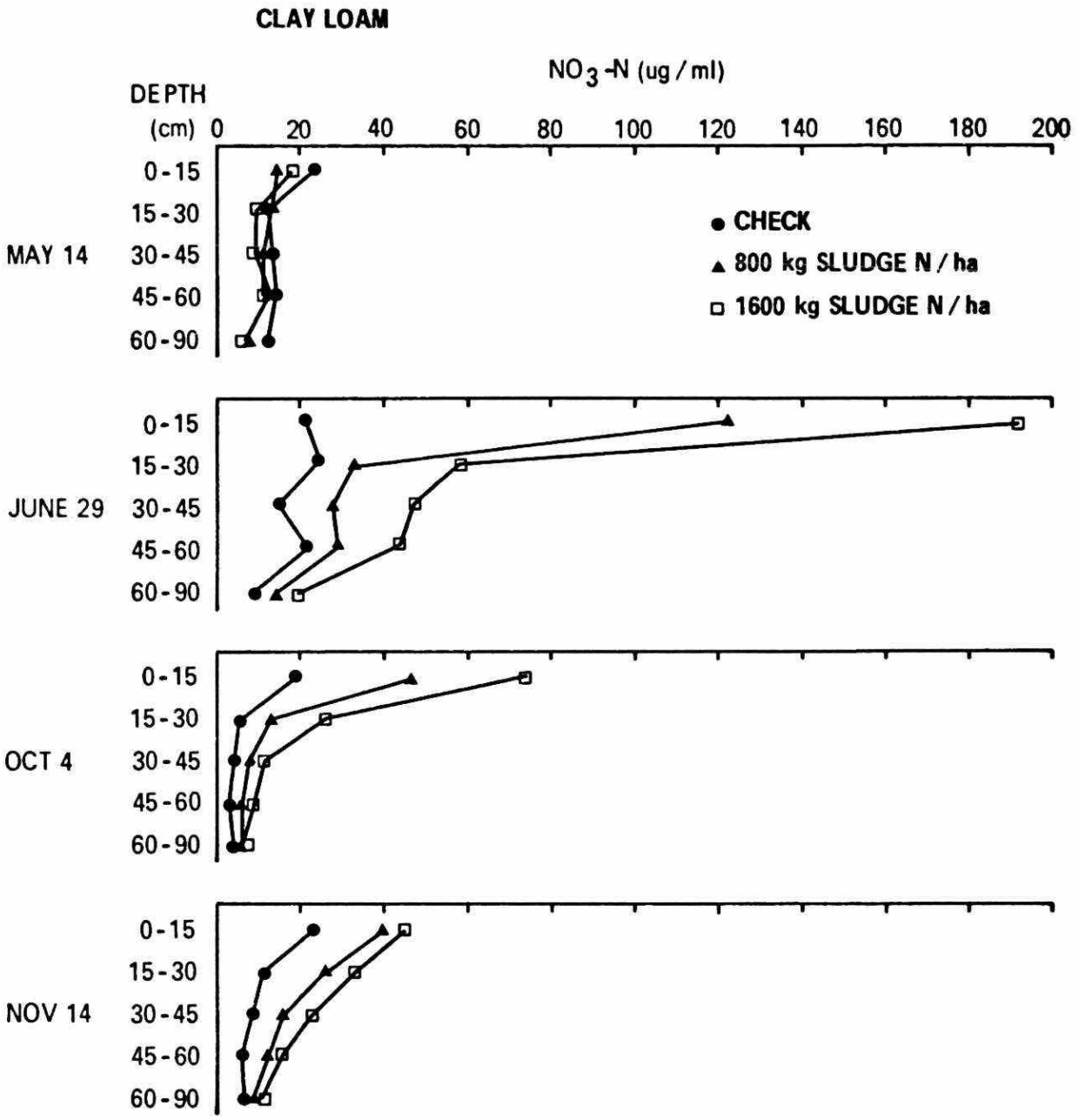

FIGURE 5. CONCENTRATION OF NO_3^--N IN A CLAY LOAM PROFILE TREATED WITH 0 (CHECK), 800, AND 1600 kg SLUDGE N/ha AS FERRIC CHLORIDE-TREATED SLUDGE APPLIED ON MAY 25, 1973.

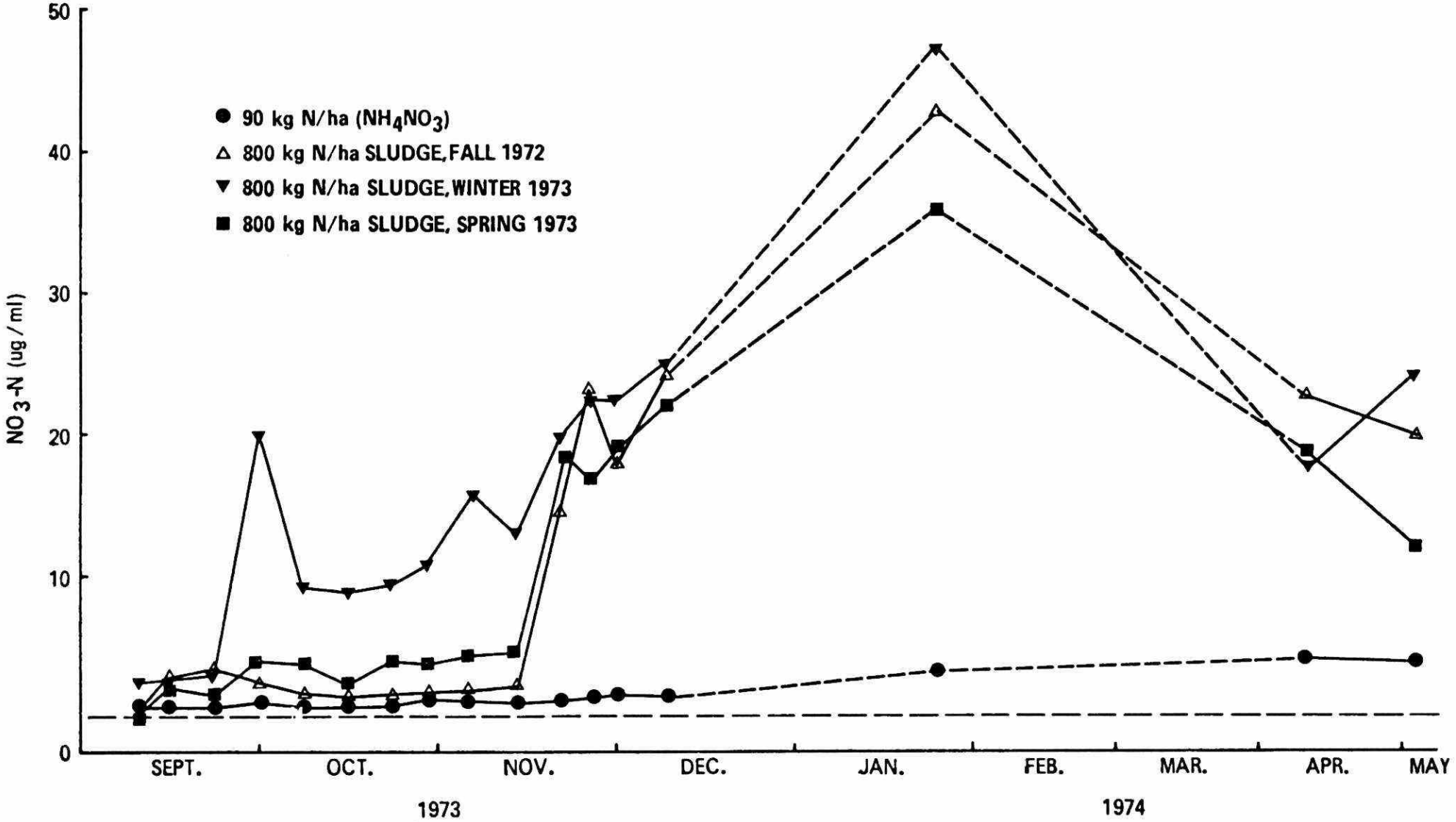

FIGURE 6. CONCENTRATION OF NO_3^--N IN SOIL SOLUTION SAMPLED PERIODICALLY AT 75 cm DEPTH IN PLOTS WHICH RECEIVED 800 kg SLUDGE N/ha IN THE FALL, 1972, WINTER, 1973, OR SPRING, 1973 AND 90 kg N/ha AS NH_4NO_3 FERTILIZER IN THE SPRING OF 1973.

It is noteworthy that NO_3^- resulting from the application of sludge in the fall of 1972 was still present in the soil profile in the spring of 1974. Apparently leaching and denitrification loss was less prevalent than might have benn anticipated during the fall, winter and spring months. These data support the conclusion that sludge should not be applied in quantities which supply more available N (NH_4^+) than the crop requires if NO_3^- pollution of ground and drainage waters is to be avoided.

Nitrogen Uptake by Crops

It has already been stated that NH_4^+ in sludge and NO_3^- are readily absorbed by plants. If the NH_4^+ content of sludge is very low, a N deficiency may occur depending on the quantity of sludge applied (5). Normally only part of the NH_4^+ and NO_3^- present in the soil profile is absorbed during the growing season. Figures 7 and 8 show the quantity of N accumulated by bromegrass and corn crops over a growing season having received different N fertilizer and sludge treatments. The values in parentheses on the abcissa in Figures 7 and 8 indicate the quantities of NH_4^+-N applied at each rate of total N applied in the sludge. Generally, the N uptake of the two crops was exceed by the amount of available N present. This difference increased as the rate of application of sludge or fertilizer increased. The uptake of N by either crop with Al-sludge was lower than with the other two sludges. This was probably caused by the abnormally high hydrocarbon content in the Al-sludge reducing the availability of N (3). Both the yield of dry matter and N concentration in the bromegrass was lower with the Al-sludge. In the corn crop, the reduction in N concentrations in the grain was primarily responsible for the lower N uptake with the lower rates of application of Al-sludge. The large difference in N uptake by bromegrass between N fertilizer and sludge may be partly attributable to the fact that all of the N fertilizer was applied in May, whereas sludge was applied in three parts; in May and after the first and second cuts.

When an excessive quantity of N is available for uptake, there is always concern for the NO_3^--N content of the crop. Many factors affect the NO_3^--N concentration in plants. One of the most important is the

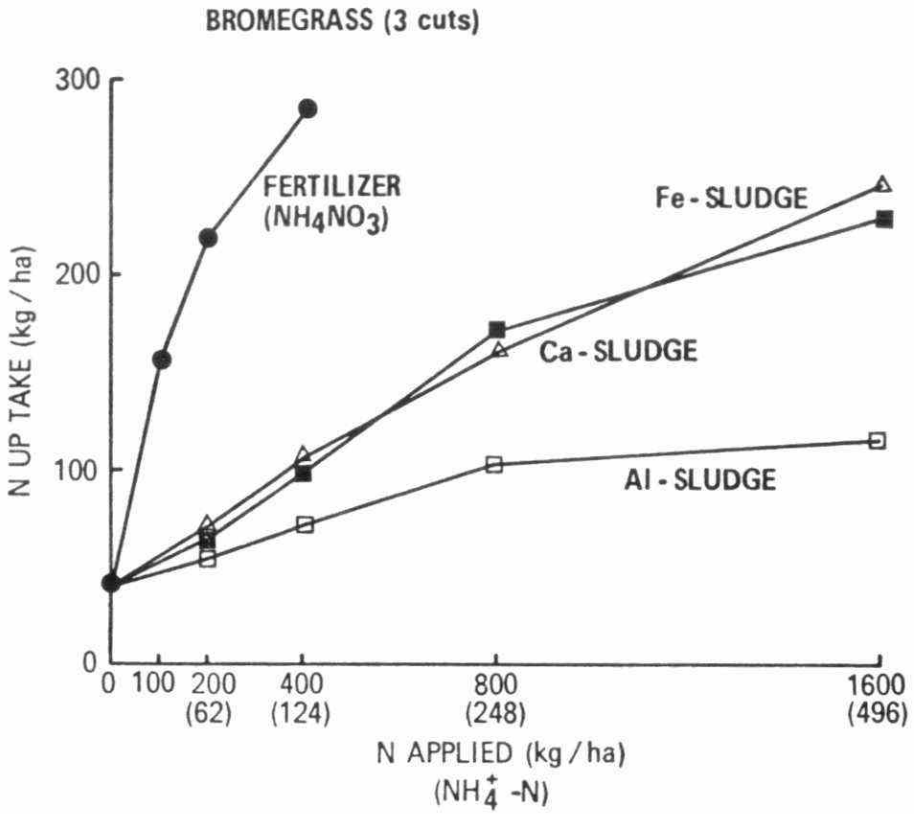

FIGURE 7. N UPTAKE BY BROMEGRASS (3 CUTS) TREATED WITH DIFFERENT RATES OF 3 CHEMICAL SLUDGES OR NH_4NO_3 FERTILIZER ON SILT LOAM SOIL IN 1973.

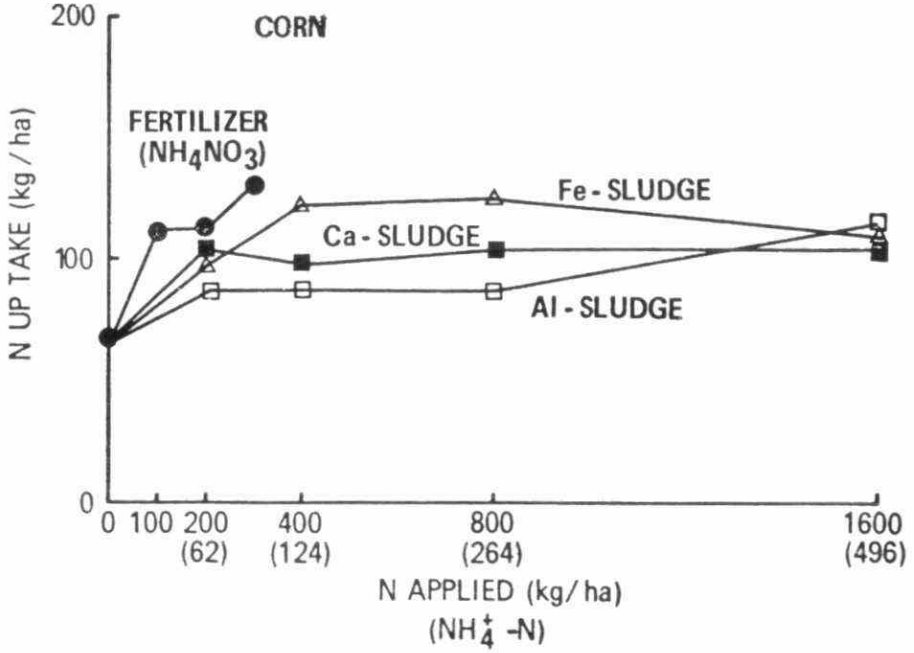

FIGURE 8. N UPTAKE BY CORN (GRAIN AND STOVER) TREATED WITH DIFFERENT RATES OF 3 CHEMICAL SLUDGES OR NH_4NO_3 FERTILIZER ON SILT LOAM SOIL IN 1973.

availability of NO_3^- in the soil. It is generally considered that a level greater than approximately 0.25% NO_3^--N in feedstuffs may present some danger to the health of ruminant animals. Some data were chosen to illustrate the effect of different rates of N fertilizer and sludges on the NO_3^--N concentration in the third cut (August 30, 1973) of bromegrass. It should be noted that all of the N fertilizer was applied in May whereas the sludges were applied one-third in May and after each of the first and second cuts. High NO_3^--N concentrations occurred only when a large quantity of available N was present (Figure 9). The low concentration of NO_3^--N in bromegrass with the highest application of Al-sludge corresponds with the apparent inhibition of nitrification of NH_4^+ when this sludge was mixed with soil. The data presented in Figure 9 along with other data obtained for the first and second cuts suggests that the NO_3^--N concentration in bromegrass will not be excessive if available nitrogen is applied in a quantity only necessary to fulfill needs for dry matter production.

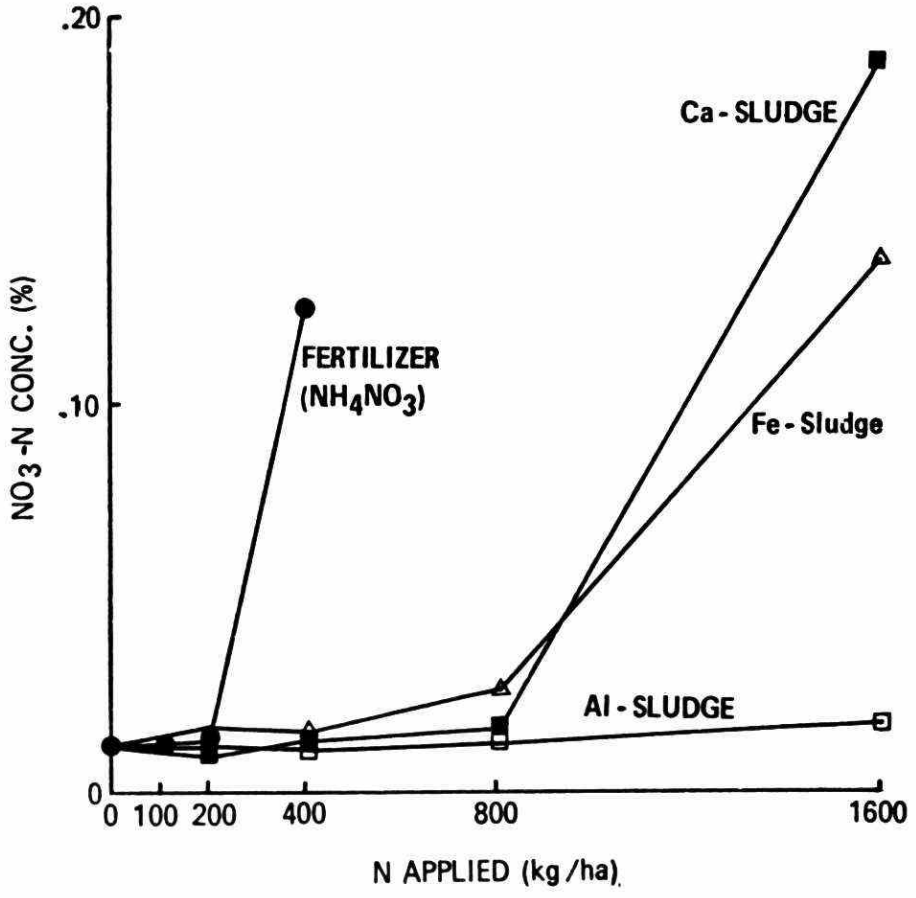

FIGURE 9. CONCENTRATION OF NO_3^--N IN BROMEGRASS TISSUES (3rd CUT 1973) AS RELATED TO DIFFERENT RATES OF THREE CHEMICALLY TREATED SLUDGES OR NH_4NO_3 FERTILIZER.

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RUNOFF AND EROSION LOSSES

W.E. Curnoe

OBJECTIVE

This section of the sludge project was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year.

EXPERIMENTAL

Design

Runoff was measured at the Elora Research Station in imperfect to poorly drained sandy clay loam soils with systematic tile drains. Field plots, 0.01 hectare, on 2% and 6% slope with suitable edging and runoff collection devices were installed in the fall of 1972. Fluid iron precipitated sludge from the North Toronto sewage treatment plant was applied to separate plots each November, January and May.

Rates of application based on the nitrogen content of the sludge were 200 kg N/ha and 800 kg N/ha on the 2% slope and 200 kg N/ha on the 6% slope. On each slope no sludge treatment received 112 kg N/ha as NH_4NO_3 in the spring. Each treatment was replicated twice.

After each runoff event the volumes of water collected were measured, samples taken and tanks emptied.

Water Analysis

Soluble nitrogen and phosphorus in the water samples were determined directly using an automated analytical technique after passing through a 0.45μ filter. To determine total nitrogen and phosphorus, the water samples were digested with H_2SO_4-H_2O_2 (Thomas, 1967), and then the concentration was determined using an automated analytical technique.

The metals: Cd, Cu, Ni, Pb and Zn were determined by atomic absorption after the water samples were passed through a 0.45μ filter, chelated with APDC* and extracted with MIBK**. Acid extractable Cd,

* Pyrrolidine carbodithioc acid ammonium salt

** Methyl isobutyl ketone

Cu, Ni, Pb and Zn were digested with aqua regia, and then the concentrations were determined by atomic absorption.

Mercury content of filtered (0.45μ) water samples was determined by flameless atomic absorption (Hamm 1973). Sediment collected on the filters was digested using low temperature aqua regia before mercury determination.

RESULTS AND DISCUSSION

Precipitation and Runoff Events

Runoff events are directly related to precipitation patterns. The total precipitation for the period November 1972 to August 1974 was 64.6 inches, which is slightly above the 30-year average. Compared to the 30-year average, 1973 and 1974 have had wet winter and spring periods and dry summer periods. As a consequence eight runoff events have occurred each year between January and May. These events have resulted from either snow melt or rain on heavy snow accumulation. During the 1973 summer period there were only three storms with intensity great enough to cause appreciable runoff. So far this summer there have been two events. In the fall of 1973 there was one event directly after the fall application of sludge.

Runoff Losses

The losses of total and soluble nitrogen in runoff during a one year period are shown in Table 1. Nitrogen losses were highest following the winter application of sludge, with 90% of this loss occurring during January - May as a result of the larger number of runoff events. The fall and spring applications did not significantly increase nitrogen losses when compared to the no sludge treatment.

The effect of increasing the slope from 2% to 6% resulted in no significant increase in the amount of nitrogen lost. This is thought to arise from the fact that the majority of nitrogen losses occur during the winter months, when the soil is in a frozen state. Differences due to slope might have been found if more runoff events had occurred during summer when soil erosion is more likely. A four fold increase in the rate of winter applied sludge on the 2% slope doubled the nitrogen loss (Table 1).

Table 1. Runoff Losses of Total and Soluble Nitrogen for a One Year Period.

Slope and Treatment	Sludge Application Time*						No Sludge	
	Fall		Winter		Spring			
	Total N	Soluble N	Total N	Soluble N	Total N	Soluble N	Total N	Soluble N
	kg/ha							
6% Slope								
200 kg N/ha from sludge	6.67	1.51	12.68	11.45	4.07	0.54		
112 kg N/ha from NH_4NO_3							5.3	.70
2% Slope								
200 kg N/ha from sludge	5.32	0.82	17.51	4.87	6.01	0.69		
800 kg N/ha from sludge	11.18	5.22	40.77	25.57	6.86	0.95		
112 kg N/ha from NH_4NO_3							6.57	0.71

* One Year Time Periods
Fall - Nov. 1972 - Nov. 1973
Winter - Jan. 1973 - Jan. 1974
Spring - May 1973 - May 1974
No Sludge - May 1973 - May 1974

Nitrogen losses during January to May 1974 were approximately a quarter of those occurring in the same period of 1973. As a consequence, differences in loss of nitrogen resulting from the various sludge application dates will not be as great as reported here for 1973.

Phosphorus losses were extremely low in all cases with no significant difference between any sludge application time and the no sludge treatment (Table 2). This may be due to the low solubility of phosphorus.

Greater differences might have occurred had there been a summer with more intense rainfall resulting in larger amounts of soil lost.

Extreme losses of nitrogen and phosphorus from the fall application in 1973 resulted from a runoff event which immediately followed the fall application of sludge (Table 3). The volume of sludge increased the volume of runoff during this period, and intensified the nutrient losses from the higher rate of application as compared to the lower rate. On this runoff event, steeper slope resulted in a greatly increased loss of nitrogen and phosphorus.

Heavy metal losses were generally very small and were not noticeably increased by sludge application (Table 4 to 6) except where the sludge was washed off immediately after the 1973 fall application (Table 6). Total metal losses from the eight runoff events, January 1974 - May 1974, were of the same order of magnitude as the one event on June 7, 1973. The small losses of heavy metals are largely due to only small amounts of metals in the sludge applied, and to few runoff events when the soil was not frozen.

CONCLUSIONS

Runoff losses in 1973 were generally less than would be expected in a year of normal precipitation pattern (compared to thirty year average).

Unusual events may occur in any year, as experienced in the fall of 1973, and emphasize the importance of considering soil conditions, snow cover, and weather probabilities before deciding to apply sludge.

Table 2. Runoff Losses of Total and Soluble Phosphorus for a One Year Period

Slope and Treatment	Sludge Application Time*						No Sludge	
	Fall		Winter		Spring			
	Total P	Soluble P	Total P	Soluble P	Total P	Soluble P	Total P	Soluble P
				kg/ha				
6% Slope								
200 kg N/ha from sludge	2.07	0.66	2.84	0.86	1.60	0.16		
112 kg N/ha from NH_4NO_3							1.77	0.16
2% Slope								
200 kg N/ha from sludge	1.33	0.21	2.52	0.58	1.50	0.16		
800 kg N/ha from sludge	2.11	0.48	3.00	1.17	1.45	0.15		
112 kg N/ha from NH_4NO_3							6.35	0.12

* One Year Time Periods
  Fall - Nov. 1972 - Nov. 1973
  Winter - Jan. 1973 - Jan. 1974
  Spring - May 1973 - May 1974
  Check - May 1973 - May 1974

Table 3. Nitrogen and Phosphorus Losses From Runoff, Nov. 16, 1973.

Slope and Treatment		Nitrogen		Phosphorus	
		Total	Soluble	Total	Soluble
		kg N/ha		kg P/ha	
6% Slope					
200 kg N/ha	Fall	21.20	4.04	4.18	0.17
2% Slope					
200 kg N/ha	Fall	3.29	3.03	0.90	0.07
800 kg N/ha	Fall	99.12	40.61	13.04	1.27

Table 4. Acid Extractable Metals in Runoff, June 7, 1973.

Slope and Treatment	Cd	Cu	Pb	Ni	Zn	Hg
	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}
6% Slope						
200 kg N Fall	0.9	16.3	23.4	16.3	115.1	<0.1
Winter	0.5	14.3	21.7	15.0	93.4	<0.1
Spring	0.7	10.9	23.7	15.2	73.8	<0.1
Check	0.4	12.4	18.7	13.0	86.9	<0.1
2% Slope						
200 kg N Fall	1.2	35.3	54.4	27.5	276.7	<0.1
Winter	0.8	36.0	55.5	26.6	251.2	<0.1
Spring	1.2	30.5	49.9	20.2	224.2	<0.1
800 kg N Fall	1.1	25.0	37.4	15.1	190.8	<0.1
Winter	1.3	42.0	65.2	33.0	298.9	0.2
Spring	1.1	37.8	58.8	28.8	284.6	0.1
Check	0.9	30.1	46.3	24.5	217.8	0.1

Table 5. Filtered Metals in Runoff, June 7, 1973.

Slope and Treatment	Cd	Cu	Pb	Ni	Zn	Hg
	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}	kg/ha X 10^{-3}
6% Slope						
200 kg N Fall	<.04	0.3	<0.4	<0.2	0.3	<0.1
Winter	<.04	<0.3	0.7	<0.2	2.8	<0.1
Spring	<.04	0.3	<0.7	<0.2	1.1	<0.1
Check	<.04	0.4	<0.7	<0.2	0.7	<0.1
2% Slope						
200 kg N Fall	<.03	0.3	<0.3	<0.2	0.2	<0.1
Winter	<.03	0.2	<0.5	<0.2	0.2	<0.1
Spring	<.03	<0.3	<0.8	<0.2	0.2	<0.1
800 kg N Fall	<.03	0.4	0.6	<0.2	0.3	<0.1
Winter	<.03	0.3	<0.6	<0.2	0.2	<0.1
Spring	<.03	0.3	<0.3	<0.2	0.2	<0.1
Check	<.03	0.2	<0.6	<0.2	0.2	<0.1

Table 6. Heavy Metals in Runoff From Fall 800 kg N/ha, Nov. 16, 1973.

	Cd	Cu	Pb	Ni	Zn	Hg
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Acid Extractable	0.0356	1.34000	1.5256	0.0263	2.9299	0.0149
Filtered	0.0001	0.0026	0.0093	0.0014	0.0208	0.00006

High rates of application can increase nutrient runoff, and stress the need to restrict application rates to that required for crop growth.

Difference in slope appear to have little effect on runoff loss, particularly in winter when soil is frozen and snow melt is confined to the surface.

Heavy metal losses tend to be small particularly where sludge of low metal content is used: the mobility of metals at higher concentrations cannot be predicted from the present work.

Caution should be exercised when trying to draw any firm conclusions based on one year's data.

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SOME MICROBIOLOGICAL ASPECTS OF THE LAND DISPOSAL OF SLUDGE

by

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INTRODUCTION

Since May, 1973 we have attempted to establish the numbers of some groups of indicator bacteria in run-off waters and sludges, and to determine the presence or absence of such pathogenic types as members of the genera Salmonella and Shigella in sludges, run-off waters and on plant material harvested from plots receiving these sludges.

To date there have been thirteen run-off events involved in this study. This has involved the examination of duplicate aliquots from 274 samples. The three sludges have each been applied ten times providing 30 samples for examination.

In 1973 samples from all corn and grass plots at the Elora Research Station, Ontario, were examined. This number proved too great to handle within a reasonable time. In 1974 the number of samples of corn and grass has been reduced. However, samples have been obtained from all research stations.

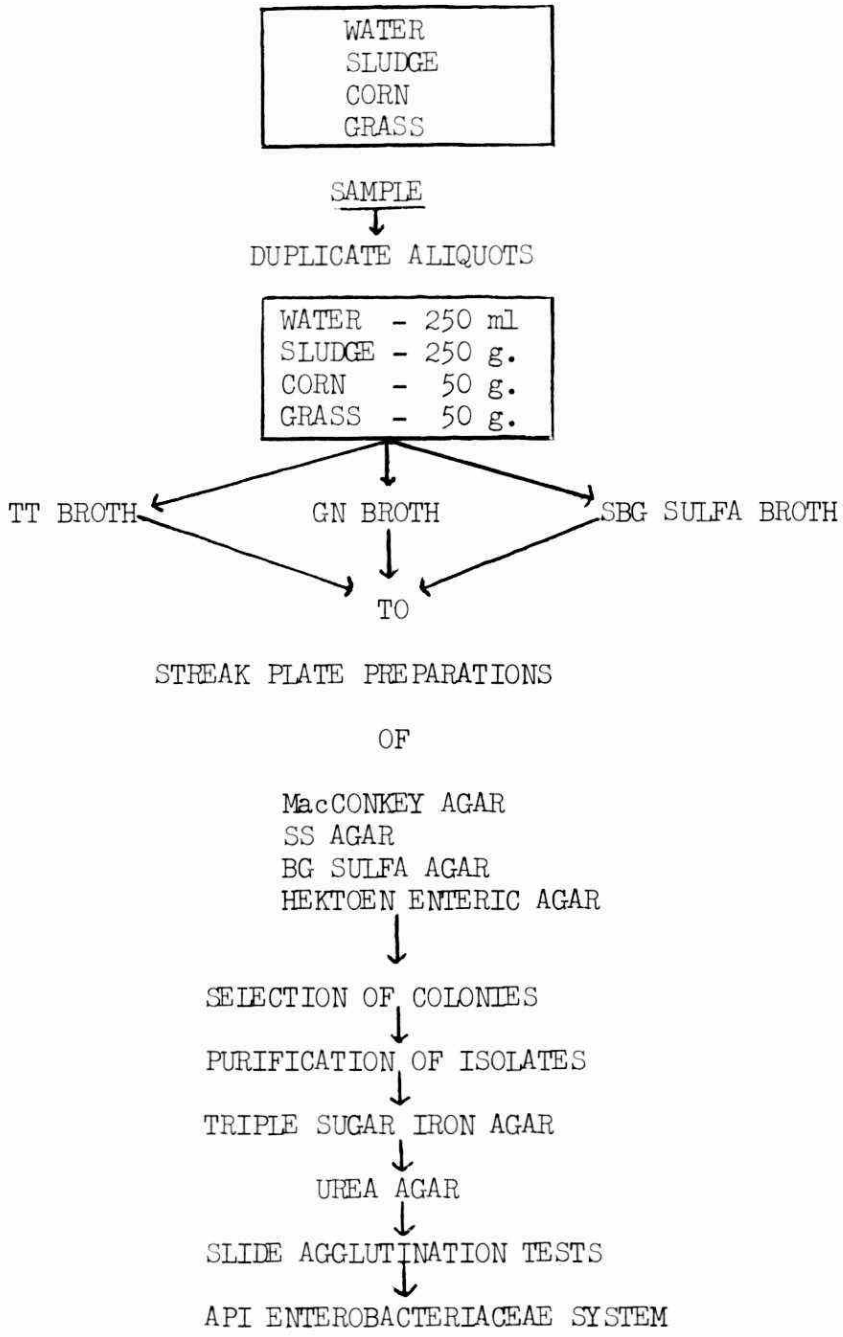
Sludge and run-off water samples continue to be submitted to the Ontario Ministry of Health for the detection of viruses.

METHODS

Sludges and Run-off Waters

Samples of these have been examined as soon as possible following the application or collection. In 1974 the amount of such materials examined for the presence-absence of Salmonella-Shigella forms has been increased to 250 grams in the case of the sludges and 250 ml in the case of the run-off waters. Such amounts were added to duplicate flasks of three selective enrichment media. The flow diagram following indicates the details of this examination.

DETECTION OF SALMONELLA - SHIGELLA



The most probable numbers of coliforms, and faecal coliforms continues to be estimated by a multiple tube dilution procedure employing: Lauryl Trytose Broth, Brilliant Green Bile Broth, and EC Medium at 44.5°C. The most probable number of faecal streptococcus is being estimated by a multiple tube procedure employing KF Streptococcus Broth.

Since July 1974 run-off waters from ten of the 22 plots are being examined. Four of these are control plots and six are test plots receiving the greater sludge application of 714 lb N/acre at the alloted times.

Corn and Grass Samples

The corn plant samples were obtained from the three research stations at the time of thinning. Samples were also obtained from a site remote from the application of the sludges.

In the case of the research stations the plants were obtained from each of three plots receiving each of the three sludges (lime, alum, iron) at 1600 Kg N/ha, and from the three plots which had received ammonium nitrate at 200 Kg N/ha.

Corn plant samples were also obtained from three sites on an Elgin County farm. This land has never received domestic waste sludge, but has received animal manure and chemical fertilizer.

The grass samples were obtained from each of three plots receiving the lime, alum and iron sludges at 1600 Kg N/ha and the ammonium nitrate at 200 Kg N/ha at the Elora Research Station.

This year the plant materials have been collected, cut into short sections and distributed in 50 gram aliquots to duplicate flasks of three selective enrichment media. The media presently being used are:

Tetrathionate Broth (Difco #0491);
Selenite Br. Green Sulfa Broth (Difco #0715); and,
GN Broth (Difco #0486).

The object in using three such media is to increase the chance of detection.

The primary plating media presently in use are:

MacConkey Agar (Difco #0075);

BG Sulfa Agar (Difco #0717);
Hektoen Enteric Agar (Difco #0853); and,
SS Agar (Difco #0074).

RESULTS

Sludge and Run-off Waters

I do not with to subject you to a perusal of all the results of the examinations of the samples of the three sludges and the numerous samples of run-off waters. Table 1, below, provides some idea of the numbers of indicator organisms encountered in one sludge.

TABLE 1. AVERAGE NUMBER OF SOME INDICATOR ORGANISMS IN NORTH TORONTO SLUDGE (IRON) OVER A PERIOD OF ONE YEAR AND NINE SAMPLES.

	Number of Organisms/100 g		
	MAXIMUM	AVERAGE	MINIMUM
Total Coliforms	19,500,000	2,583,000	12,500
Faecal Coliforms	2,400,000	291,000	0
Faecal Streptococci	16,000,000	4,126,000	295,000

It is the North Toronto sludge which is being applied to the run-off plots. Obviously large numbers of coliforms and streptococci are being added. A comparison of the numbers normal to the sludge and the numbers in the run-off waters usually indicates a great reduction. In addition the number of such indicator organisms found in waters from the control plots is at times equal to or greater than the numbers from the test plots. It is evident from Table 2 that the slope of the soil surface is a factor contributing to the numbers of organisms in the run-off water. Again the control plots are making contributions similar to the test plots.

Identification of Isolates

Run-off waters

Over 400 isolates have been obtained to date. Three hundred and thirty-two of these are not Salmonella or Shigella species. There would seem to be little indication that these waters contain Salmonella or

TABLE 2. AVERAGE NUMBER OF MICROORGANISMS IN RUN-OFF WATERS FROM APRIL 2, 1974 FROM ALL PLOTS IN EACH GROUP ON EACH SLOPE.

Microorganisms	Rate and Time of Application										
	Check		Fall*		Winter		Spring		Fall	Winter	Spring
			178 *		178		178		714	714	714
Slope	2%	6%	2%	6%	2%	6%	2%	6%	2%	2%	2%
Total Coliforms**	65,000	805,000	2,300	455,000	129,000	417,000	18,900	51,300	57,800	103,800	12,000
Faecal Coliforms**	2	1	4	0.5	0	0	1.5	2.5	1.5	0	1
Faecal Strptococci**	2,400	8,700	2,300	27,000	32,000	37,000	15,700	139,000	3,100	4,950	2,100

*Plot treatments lb N/acre.

**Estimate/100 ml MPN.

Shigella species. More isolates were obtained than their appearance on the primary plating media would justify. If these pathogenic genera are present we have not been able to demonstrate them until September, 1974. For this reason the volume of the run-off water used in culturing has been increased by five times. The samples are now being obtained from the high rate application plots only. The possible influence of this change in procedure will not become evident for some time. In the most recent group of isolates examined, two from the same water sample have been identified as Salmonella enteriditis. A possible Shigella species has also been isolated.

Sludges

About 165 isolates have been obtained. Of 45 of these one is considered to be a species of Shigella and another has been identified as Salmonella enteriditis.

The increased amount of sludge to be examined this fall may influence the number of isolates obtained.

Corn plants

Some 400 isolates have been obtained to date. Very few (17) were obtained in 1973. The remainder were obtained in 1974. None of these has been processed beyond purification.

Grass

Some 310 isolates have been obtained to date. Most of these were obtained in 1974. None of these has been processed beyond purification.

COMMENTS

Based on what I have observed to date I would make these comments:

1. The examination of sludge and run-off water for the estimation of commonly employed indicator organisms is of little value in assessing the influence of sludge on this run-off water.

2. The number of Salmonella and Shigella bacteria encountered in sludge and run-off water must be very small.

3. I presently believe that some Salmonella and Shigella forms would be able to survive for a short time in sludge and sludge-soil mixtures. If it is assumed that such bacteria are present in raw domestic waste then either the concentration is extremely low or they are subject to "die-off" before the digested sludge is produced. In either event the numbers could be very small and thus increase the difficulties of isolation. If the incidence of these organisms continues to be so very low are they a hazard in this use of sludge?

CATION DISTRIBUTION IN SOILS AS RELATED TO SEWAGE SLUDGE DISPOSAL ON LAND

by

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INTRODUCTION

When sewage sludges are used on land the cations not removed by plants, runoff or groundwater remain in the soil. It is usually assumed that the cations eventually are fixed on the exchange sites of clays and organic matter. However, in many soils Fe, Al, Ti, Mn and Ca, have been shown to move and accumulate in specific zones or concretions. The separate accumulations of Fe and Mn have been shown to take place very near to each other, (Brewer et al., 1973).

Existing variation in soil horizon thickness in Ontario has been demonstrated by Protz et al. (1968). Variations in pH, soil test Ca, Mg, NO_3, P and K in one Ontario soil series were reported by Protz (1968). These data prompted a detailed soil survey of the sewage sludge research plots used by the Guelph project.

The purpose of this paper is to demonstrate variation of soils at the macro (field plot) and micro (cation) scales. These types of data will have to be considered before final guidelines for soil sampling and analyses are accepted.

MATERIALS AND METHODS

Eight soil profiles were sampled (two from each of the four field plots) of the University of Guelph sewage sludge project. Vertical thin section (2 x 3" or 5 x 7 cm) were made from the total thickness of four soil profiles (one from each of the four plots). Horizontal thin sections were made at 6 inch (15 cm) depth intervals from each of the four soil profiles. After these thin sections were examined narrower thin sections (1 x 3" or 2.5 x 7 cm) were made of selected pedological features and used for elemental analyses by Electron Microprobe. Soils were impregnated (Vestapol and Styrene) according to the method of Altemuller (1962).

Electron microprobe analyses were only semi-quantitive for any one thin section for reasons outlined in Brewer et al. (1973).

Particle size analyses were done by sieving and the pipette method (Kilmer and Alexander, 1949) following the destruction of organic matter with H_2O_2 and dispersion by calgon (Tyner, 1949). Organic matter was determined by the wet oxidation method (Walkley, 1947). The pH determinations were done in 1:1 soil to water suspensions and in 0.01 m $CaCl_2$ (Jackson, 1958). Determination of Na-dithionite and NH_4-oxalate extractable Fe, Al and Mn were made by Atomic Absorption (Raad et al., 1969). $CaCO_3$ equivalent was determined by the HCl method (Walker, 1965).

RESULTS

The nature of the macro (field plot) variation can be visualized from the Ap horizon thickness (Figures 1, 4) and depth to Bt horizon (Figures 2, 5) $CaCO_3$ (Figures 3, 6) maps of the soils from the Milton and Cambridge corn plots. As clay content influences the amount of water passing through a soil it influences the pH and variability of $CaCO_3$.

Soils with greater clay contents (Milton) have less variation (Figures 1 - 3) as compared to coarse textured soils (Cambridge) which have a greater variation (Figures 4 - 6). These data are directly applicable to soil sampling schemes for monitoring purposes. The number of soil samples required will have to depend upon the soil being sampled or else the least number of samples required should be based on the most variable soil. The potential maximum variability of cations (Tables 1, 2, 3) with depth in a soil can be demonstrated with two profiles 12 inches (30 cm) apart (Plate 1) in the coarse textured soils of the Cambridge corn plot. Variation in clay content is as high as 20% and over 40% in $CaCO_3$ equivalent (Table 1). Variation in Na-dithionite Fe is >1.30% (5 fold), in Al up to .18% (10 fold) and .10% (10 fold) in Mn (Table 2). Variation in acid NH_4-oxalate extractable Fe is up to .28% (5 fold), in Al up to .18% (10 fold) and .08% (7 fold) in Mn (Table 3).

This variability results from the inherent fluvial parent material and the influence of trees on soil formation.

Distribution of cations within the soil profile is ultimately controlled by their solubility products, porosity of the soil and the

micro variations in the soil moisture regime. The "final" distribution of cations within the soil on the microscopic scale are best demonstrated by micrographs of the various pedological precipitates and concretions found in soils (Plates 2 - 9).

Titanium was found in the Caledon #2 soil profile from the Cambridge corn plots (Plate 2). Iron and Fe plus Mn "concentrations" were also found in the surface horizon of the Caledon #2 soil profile (Plate 2). Argillans (uncoated clay accumulations) around sand grains (Plate 3) in the Caledon #2 soil profile indicate the physical movement of $<2\mu$ particles in this soil. The accumulation of $CaCO_3$, Feri-argillans (Fe coated clay) and argillans within a 2mm distance (Plate 4) indicates the variation in soil environments over very small distances.

Beginning accumulations of Fe (Ferrans) and Fe plus Mn (Ferran-Mangans) in the Oneida #1 soil profile (Plate 5) and susequent more discrete concentrations in (Plate 6) were found in close proximity of each other. Similar pedogenic properties (Plates 8 and 9) were found in the Conestoga soil profile from the Elora corn plots. In the Oneida #1 soil profile calcans ($CaCO_3$ accumulations) are covered by argillans within 3 mm of Ferrans (Plate 7).

CONCLUSIONS

As we attempt to cycle wastes on agricultural soils for food production under environmentally safe conditions we must know the variability of cations in soils to accurately monitor the systems. If we are to set up systems that will be safe for long periods of time we must know in what forms the added materials remain in the soils.

ACKNOWLEDGEMENTS

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TABLE 1: Percent <2μ clay and $CaCO_3$ equivalent in two adjacent (12 inches) (30 cm) soil profiles of the Cambridge corn plots.

Depth inches (cm)	%<2μ		% $CaCO_3$ equivalent	
	Profile 1	Profile 2	Profile 1	Profile 2
18-20 (45-50)	22.6	3.7	.6	43.8
20-24 (50-60)	24.9	2.6	.7	46.8
24-27.5 (60-70)	25.3	3.2	1.0	47.3
27.5-31.5 (70-80)	19.5	2.0	1.8	44.5
31.5-35.5 (80-90)	17.1	2.5	5.6	41.2
35.5-39.5 (90-100)	15.8	2.8	3.0	33.2
39.5-43 (100-110)	8.3	2.0	1.1	18.6
43-47 (110-120)	8.5	3.9	1.6	15.3
47-51 (120-130)	8.8	3.2	3.3	15.9
51-57 (130-145)	8.3	3.5	1.4	17.5

Table 2: Precent Na-dithionite extractable Fe, Al and Mn in two adjacent (12 inches (30 cm)) soil profiles of the Cambridge corn plots.

Depth inches (cm)	% Fe		% Al		% Mn	
	Profile 1	Profile 2	Profile 1	Profile 2	Profile 1	Profile 2
18-20 (45-50)	1.65	.30	.15	.02	.12	.02
20-24 (50-60)	1.67	.27	.18	.01	.10	.01
24-27.5 (60-70)	1.68	.21	.19	.01	.09	.01
27.5-31.5 (70-80)	1.42	.20	.17	.01	.09	.01
31.5-35.5 (80-90)	1.26	.19	.15	.01	.08	.01
35.5-39.5 (90-100)	.94	.18	.11	.01	.06	.01
39.5-43 (100-110)	.56	.13	.06	.01	.02	.01
43-47 (110-120)	.51	.13	.05	.01	.02	.01
47-51 (120-130)	.48	.15	.05	.01	.02	.01
51-57 (130-145)	.24	.14	.05	.01	.02	.01

Table 3: Percent acid NH_4 - oxalate extractable Fe, Al and Mn in two adjacent (12 inches (30 cm)) soil profiles of the Cambridge corn plots.

Depth Inches (cm)	% Fe		% Al		% Mn	
	Profile 1	Profile 2	Profile 1	Profile 2	Profile 1	Profile 2
18-20 (45-50)	.35	.07	.19	.02	.10	.02
20-24 (50-60)	.34	.06	.18	.01	.08	.01
24-27.5 (60-70)	.33	.06	.19	.01	.07	.01
27.5-31.5 (70-80)	.29	.06	.15	.01	.08	.01
31.5-35.5 (80-90)	.25	.02	.13	.01	.06	.01
35.5-39.5 (90-100)	.22	.02	.11	.01	.06	.01
39.5-43 (100-110)	.09	.02	.06	.01	.02	.004
43-47 (110-120)	.09	.02	.06	.01	.02	.005
47-51 (120-130)	.09	.02	.05	.01	.02	.005
51-57 (130-145)	.10	.02	.05	.01	.02	.005

FIGURE 1: Ap SOIL HORIZON THICKNESS MAP OF THE MILTON CORN PLOTS

Contour Interval 5 cm.

PLOT SIZE 15 FT. x 25 FT.

20 FT.

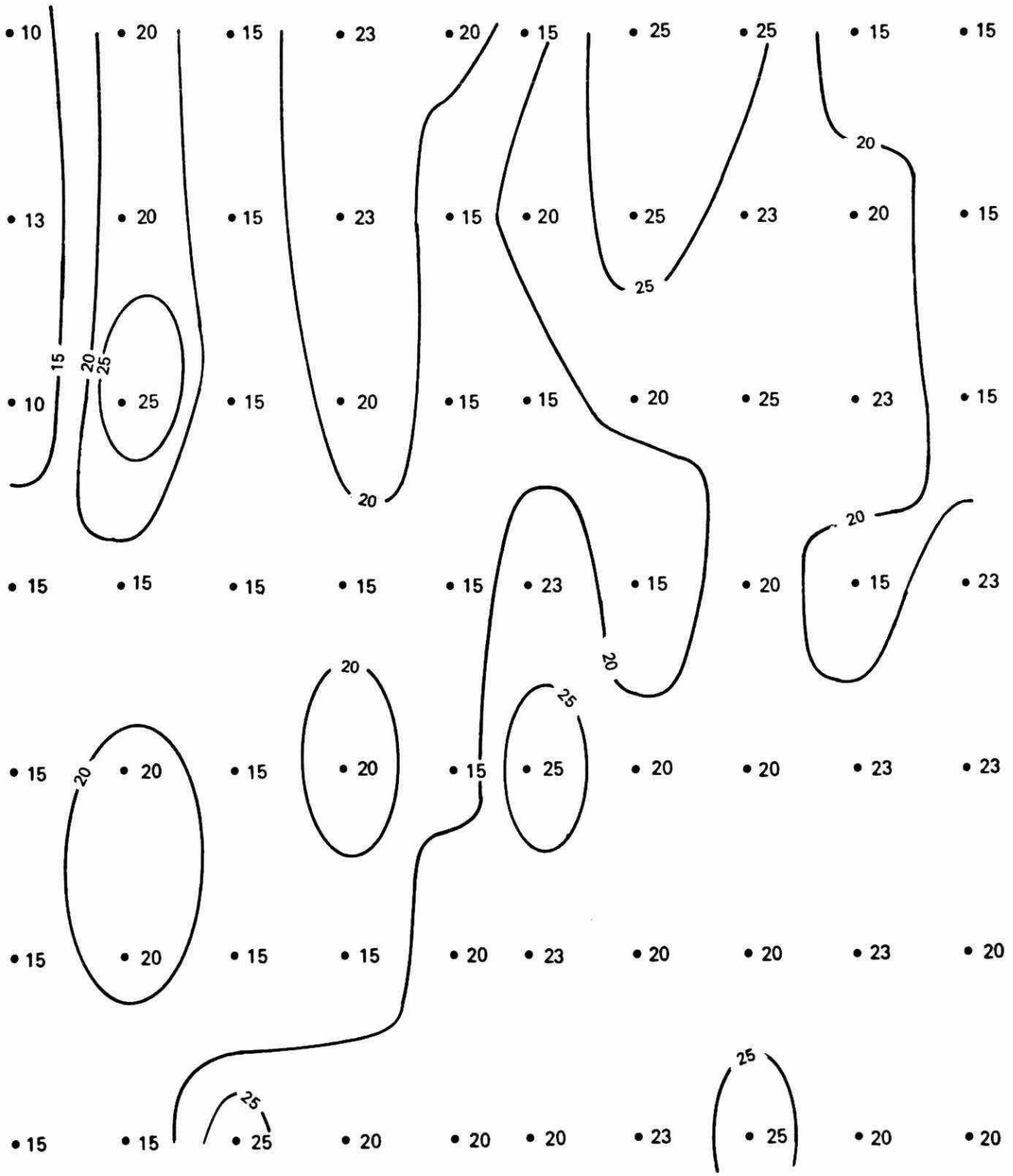


FIGURE 2: DEPTH TO SOIL Bt MAP OF THE MILTON CORN PLOT

Contour Interval 10 cm.

PLOT SIZE 15 FT. x 25 FT.

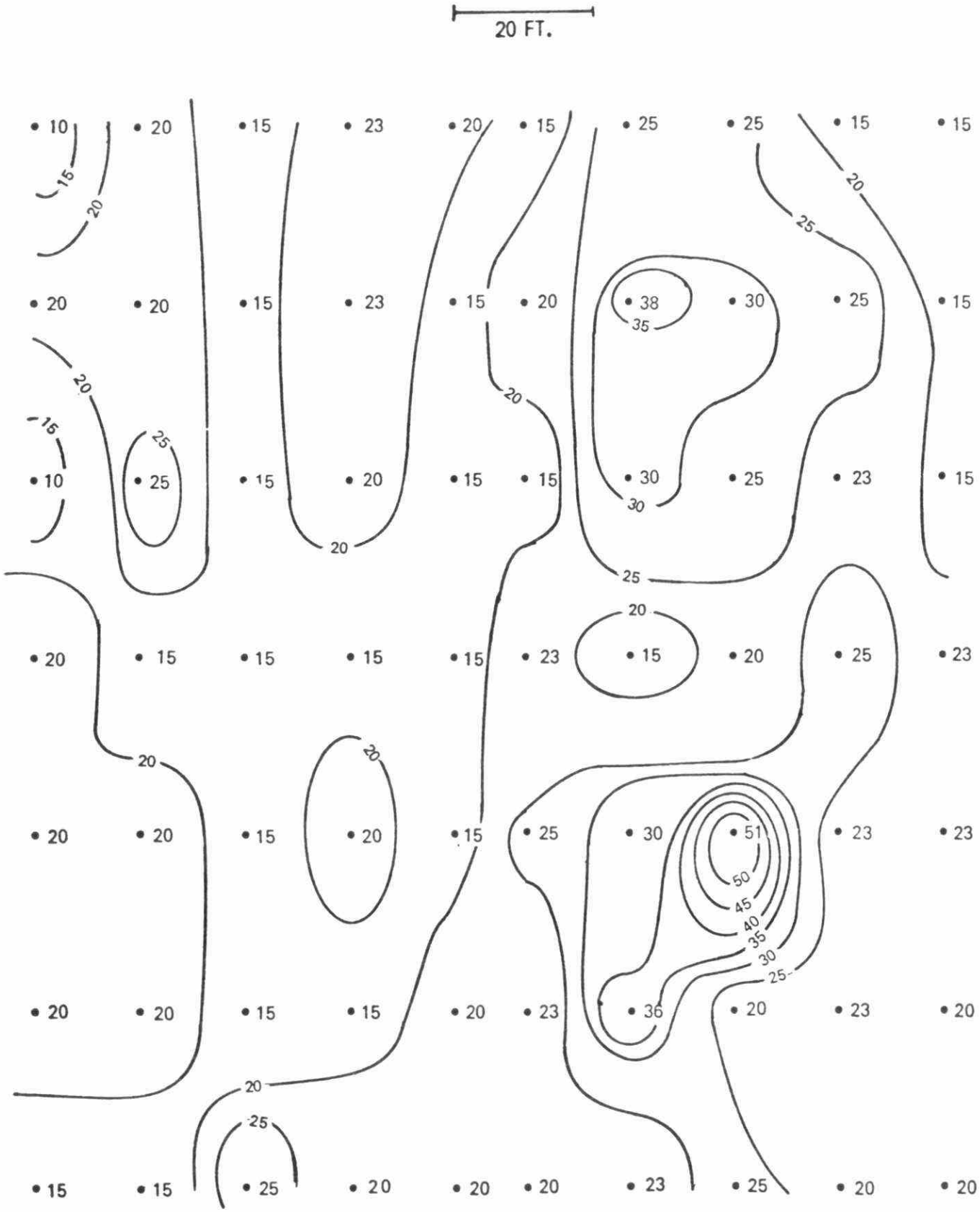


FIGURE 3: MAP OF CARBONATE DEPTH AT MILTON CORN PLOT

Contour Interval 10 cm.

PLOT SIZE 15 FT. x 25 FT.

20 FT.

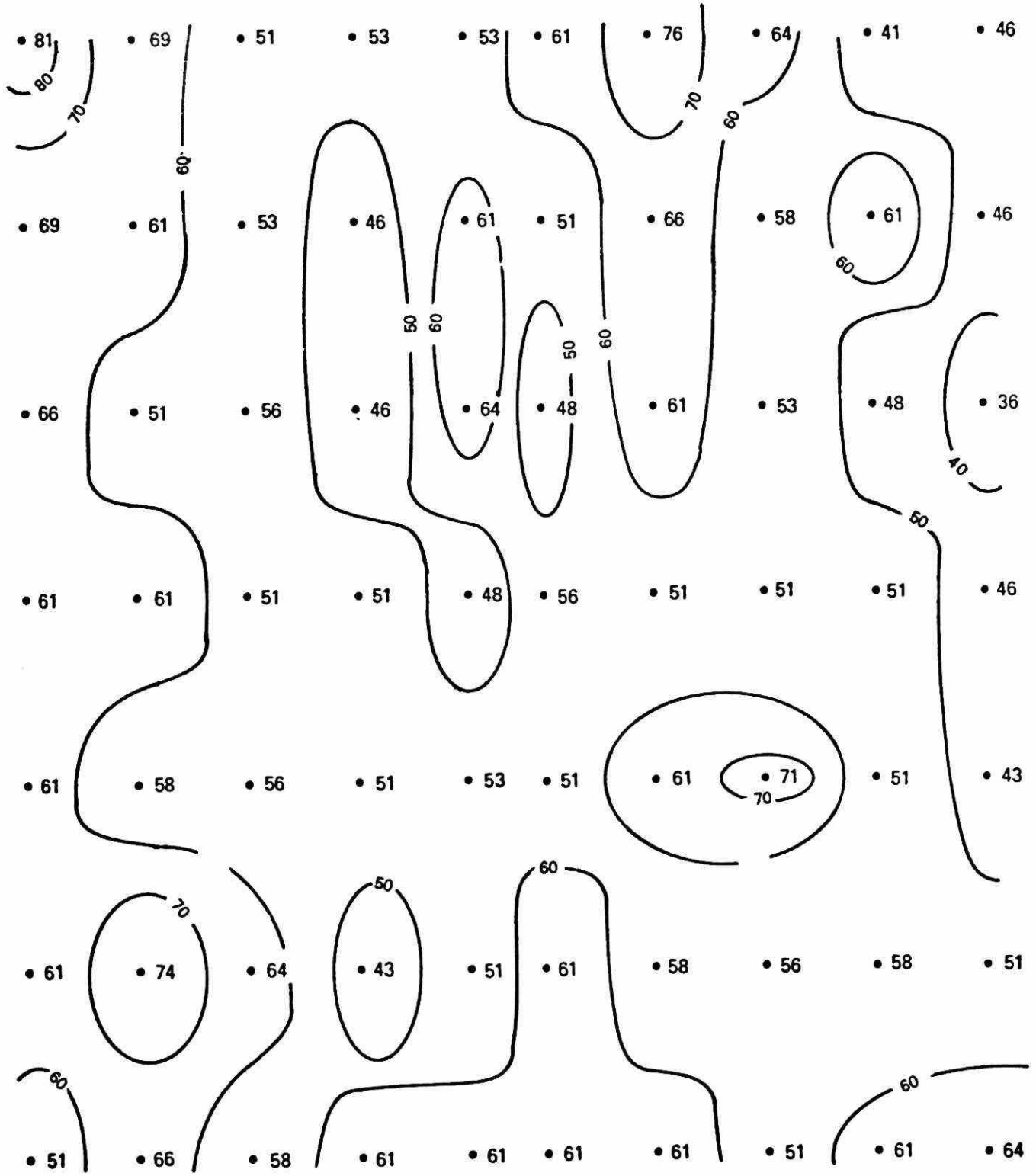


FIGURE 4: Ap SOIL HORIZON THICKNESS MAP OF THE CAMBRIDGE CORN PLOTS

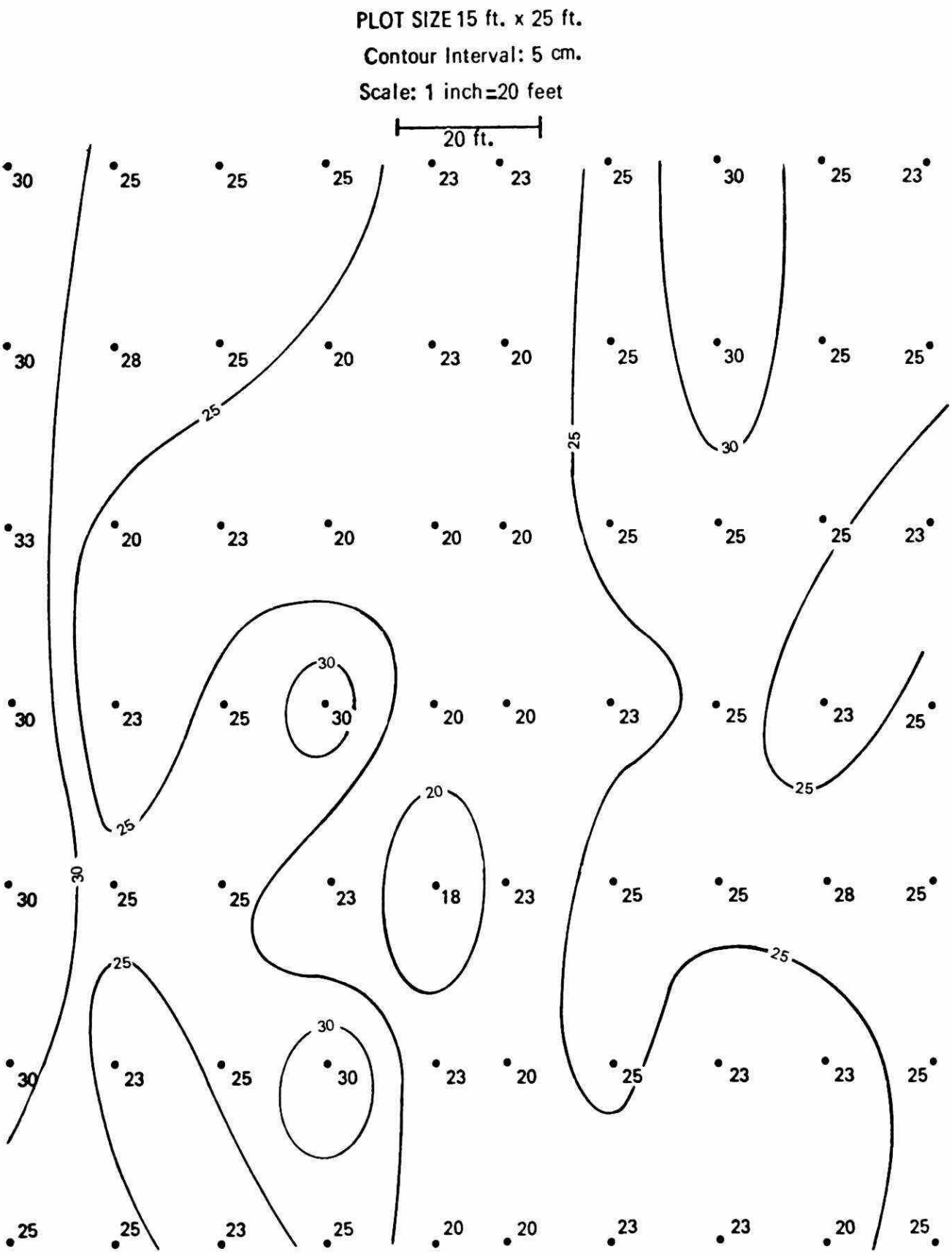


FIGURE 5: DEPTH TO SOIL Bt MAP OF THE CAMBRIDGE CORN PLOTS

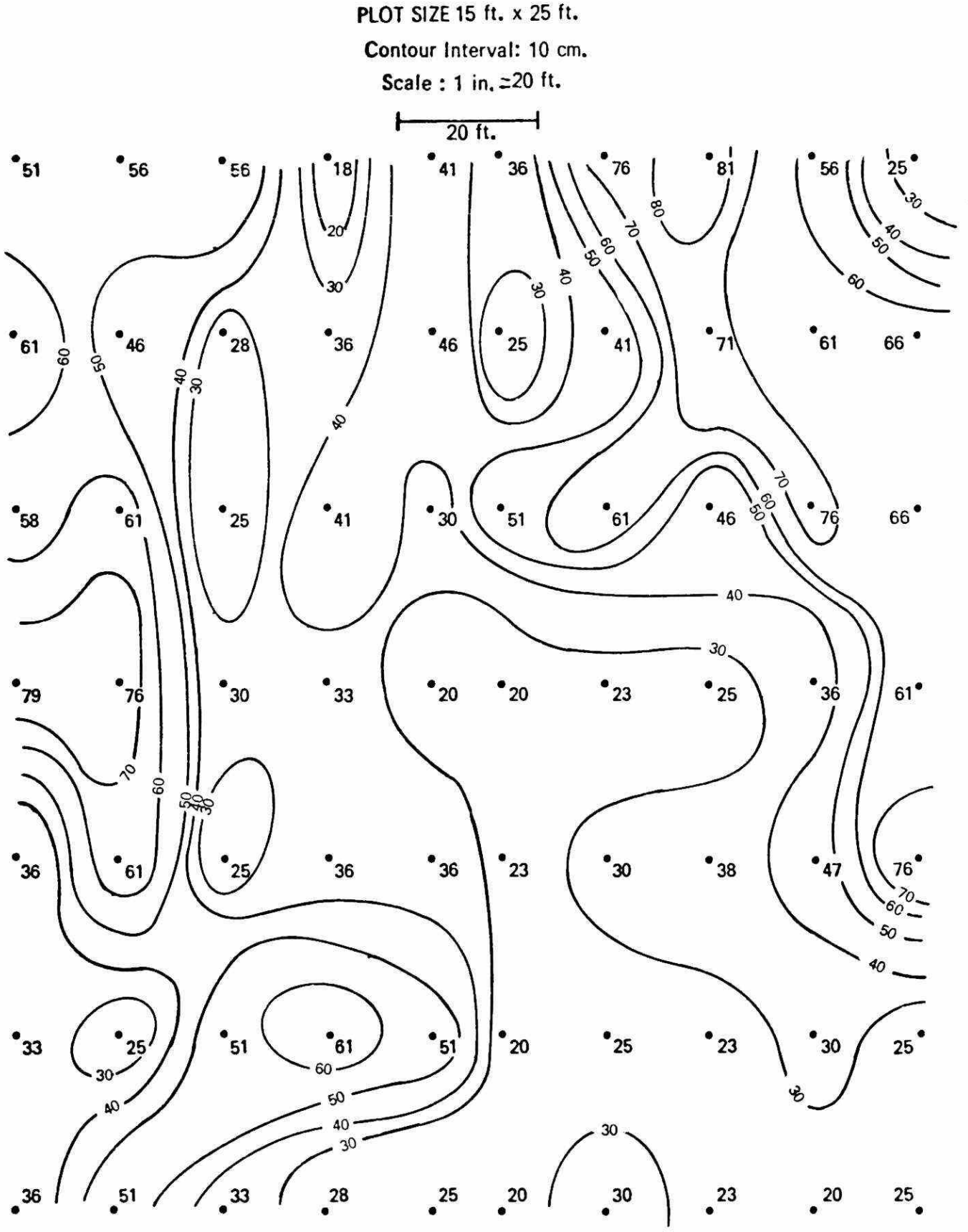
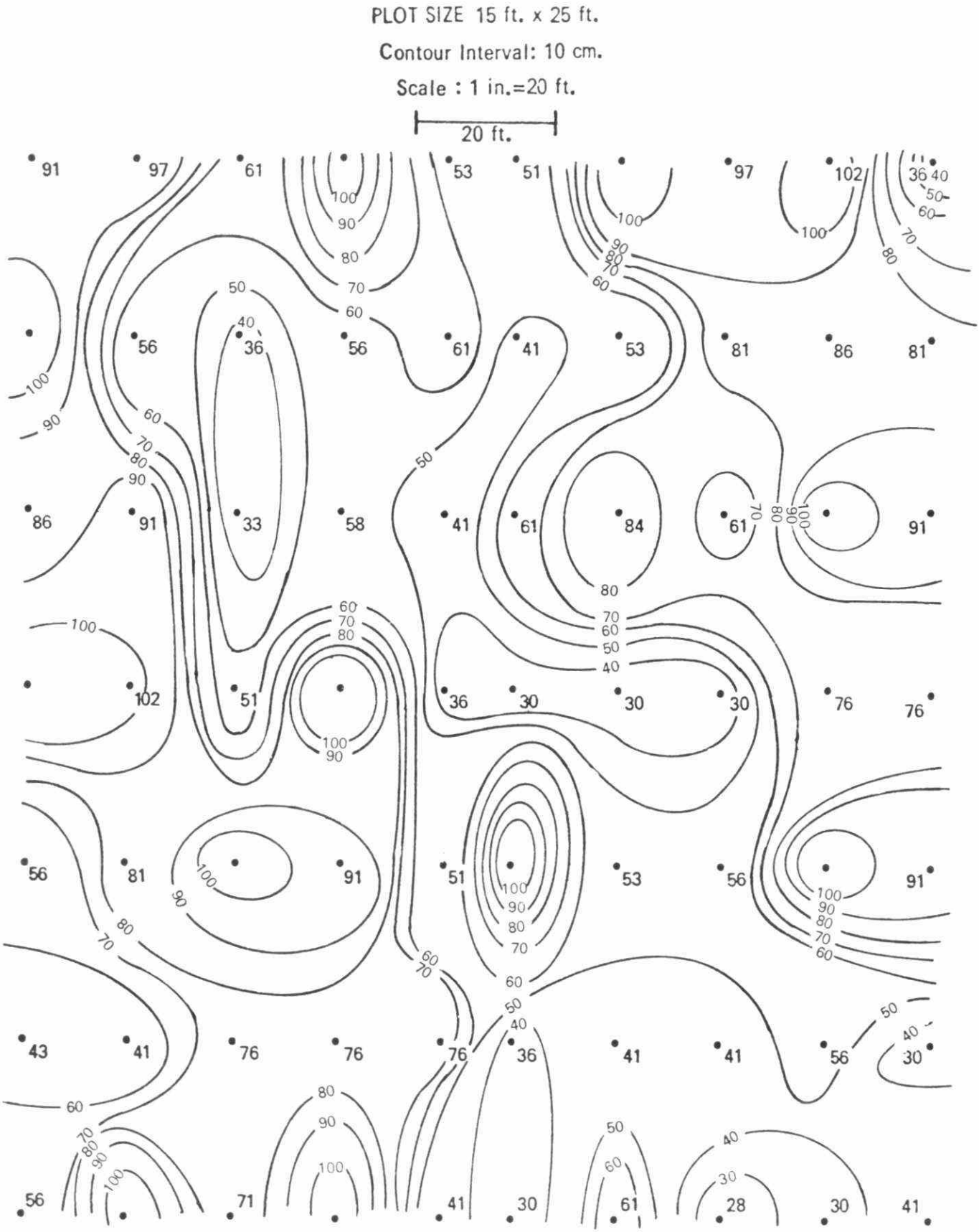


FIGURE 6: DEPTH TO SOIL CARBONATES MAP OF THE CAMBRIDGE CORN PLOTS



PLATES

Plate 1. Soil profiles variation of the Caledon soil series on the Cambridge corn plots.

Plate 2. (a) Ti; (b) Fe; (c) Fe plus Mn and; (d) organic matter accumulations at the 3 inch (7 cm) depth of the Caledon soil profile on Cambridge corn plots; length 3.2 mm.

Plate 3. (a) Argillans (uncoated clay) accumulation around (b) sand grains in the Caledon #2 soil profile at the 55.5 - 57 inch (142-144 cm) depth on the Cambridge corn plots; length 1.0 mm.

Plate 4. Accumulation of (a) $CaCO_3$, (b) Feri-argillans (Fe coated clay and (c) argillans (uncoated clay) at the 40 inch (102 cm) depth in the Caledon #2 soil profile on the Cambridge corn plots; length 2.1 mm.

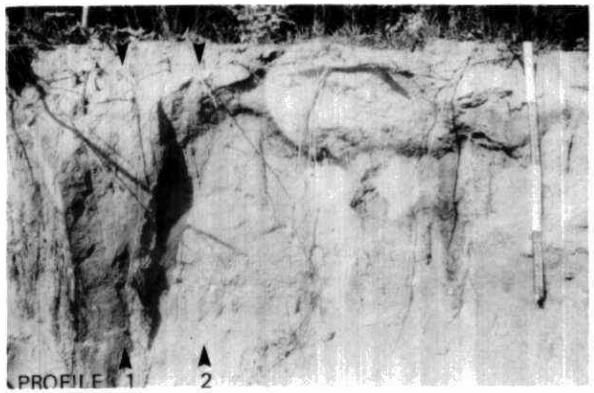
Plate 5. Initial accumulation of a (a) Ferran-Mangan (Fe plus Mn) at the 9.5 inch (24 cm) depth of the Oneida #1 soil profile on the Milton corn plots; length 2.1 mm.

Plate 6. (a) Ferran-Mangan at the 9.5 inch (24 cm) depth of the Oneida #1 soil profile on the Milton corn plots; length 2.1 mm.

Plate 7. (a) Calcan ($CaCO_3$); (b) argillan (clay) and; (c) Ferran (Fe) accumulations at the 27.5 - 29 inch (71 - 73 cm) depth in the Oneida #1 soil profile on the Milton corn plots; length 3.2 mm.

Plate 8. Initial accumulation of a (a) Ferran-Mangan and (b) Argillan at the 26.5 - 28.5 inch (68 - 72 cm) depth in the Conestoga soil profile on the Elora corn plots; length 2.6 mm.

Plate 9. (a) Ferran (Fe); (b) Ferran-Mangan accumulations at the 21.5 inch (54 cm) depth in the Conestoga soil profile on the Elora corn plots; length 1.0 mm.



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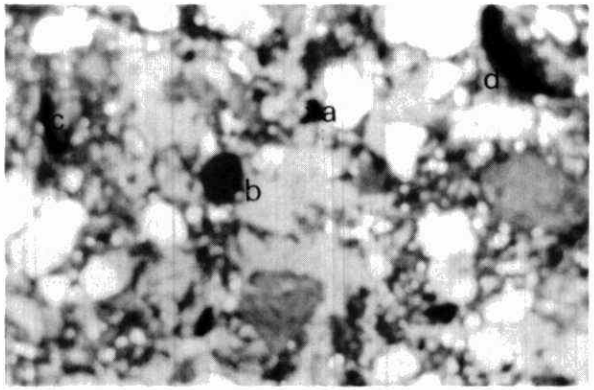

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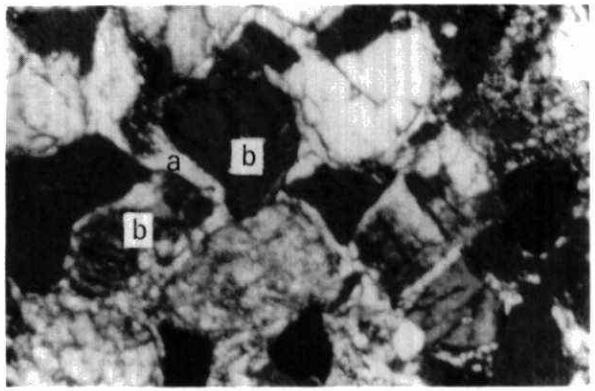

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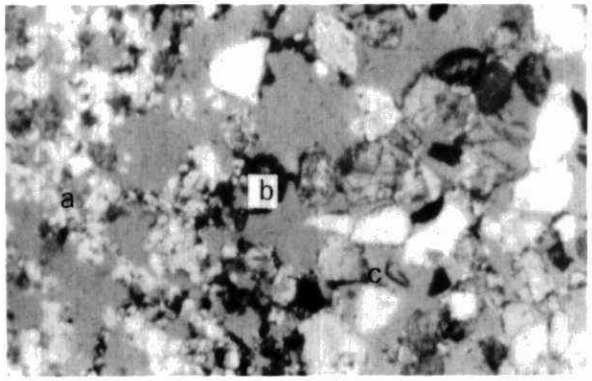

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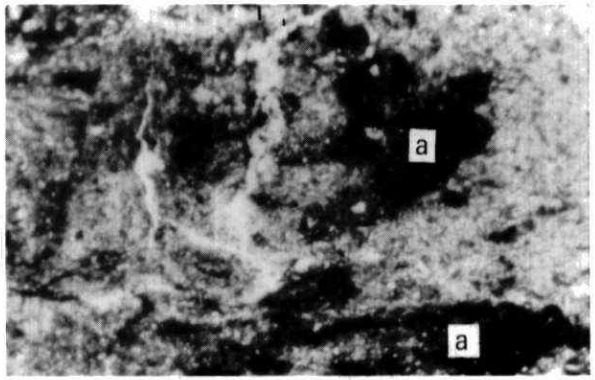

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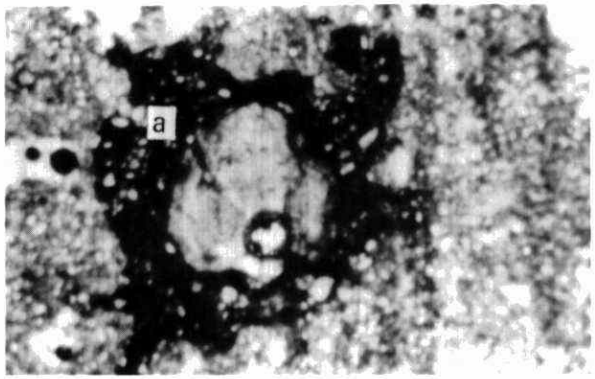

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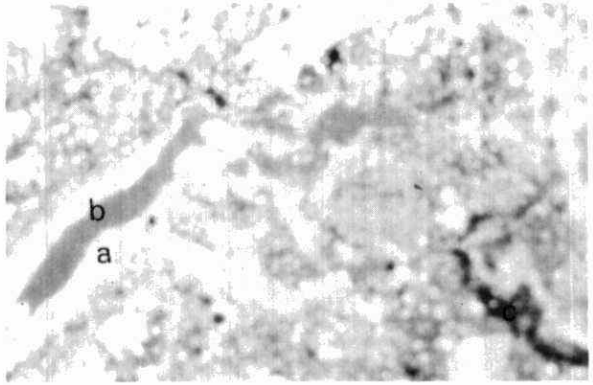

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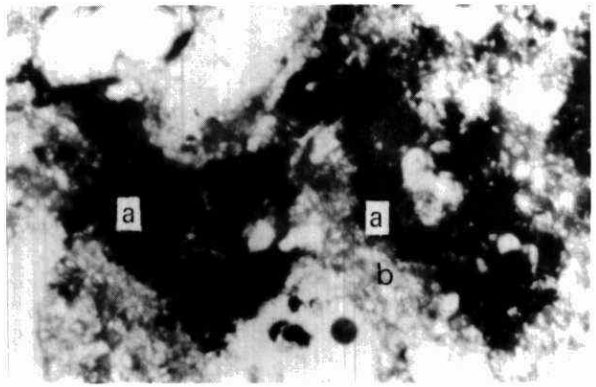

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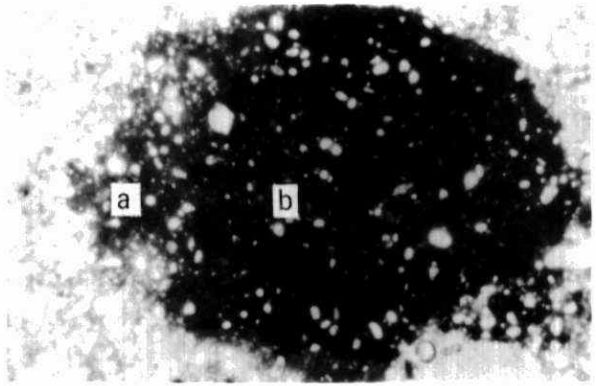

9

DISPOSAL OF CHEMICAL SEWAGE SLUDGES ON LAND AND THEIR EFFECTS ON PLANTS, LEACHATE AND SOIL SYSTEMS

by

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Wastewater Technology Centre

Environmental Protection Service

Environment Canada

1 INTRODUCTION

Sewage sludges have been disposed on land for several decades and have been profitably used as fertilizers and soil improving agents in agriculture. Direct application of liquid digested sludges on land has regained popularity in North America since mid-sixties (Conn, 1970) but this method is not without problems. Hinesly and Sosewitz (1969) have reported that sludge application rates which supply nitrogen in amounts greater than those needed for crop production will increase nitrate levels in drainage water. Webber (1972), Rohde (1962) and Petterson (1971) have reported crop damage and metal toxicities to plants and soils from heavy sludge applications.

Sewage phosphorus removal programs in Ontario by using alum, ferric chloride or lime as precipitating agents have introduced chemical sewage sludges to the environment. Nutrients, metals and other organic constitutents are enhanced in such sludges and could become potential environmental hazards. By 1976 (Davies, 1971) sludges will amount to approximately nine million tons and may pollute water, soil and plants if uncontrolled quantities are disposed on land.

Since large quantities will be disposed on land for agricultural usage, it is essential that long-term environmental effects on plants, groundwater and soil systems are assessed. To aid in the assessment, an intensive lysimeter syudy was undertaken in 1972 at the Wastewater Technology Centre, Burlington. Three chemically precipitated digested sewage sludges at three annual rates of application on two types of soils with orchard grass plantation are under investigation.

2 MATERIALS AND METHODS

2.1 Experimental Lysimeters

Sixty-six fiberglass lysimeters, 30 cm in diameter, 1.8 m in depth were housed in an environmentally controlled trailer. The tops of the lysimeters project about 7.5 cm through the roof of the trailer and were subjected to normal ambient and atmospheric conditions. Facilities were provided at the bottom of the lysimeters for leachate collection.

2.2 Experimental Design

A randomized block design with two soil types, three replications and eleven treatments was used. The treatments are:

1. Control
2. NPK @ 336, 112 and 112 kg/h/year
3. Alum sludge @ 300 Kg TKN/ha/year
4. Alum sludge @ 600 Kg TKN/ha/year
5. Alum sludge @ 900 Kg TKN/ha/year
6. Iron sludge @ 300 Kg TKN/ha/year
7. Iron sludge @ 600 Kg TKN/ha/year
8. Iron sludge @ 900 Kg TKN/ha/year
9. Lime sludge @ 300 Kg TKN/ha/year
10. Lime Sludge @ 600 Kg TKN/ha/year
11. Lime sludge @ 900 Kg TKN/ha/year

2.3 Soils used

The two soils used in the experiment were loamy sand from Cambridge and silt loam from Guelph, Ontario. A brief description of soils is given in Table 1.

TABLE 1. DESCRIPTION OF SOILS USED

Soil Type	Horizon Depth (cm)	pH	Organic Matter %	Sand %	Silt %	Clay %	Bulk Density g/cm^3
Loamy Sand	A-19	7.8	2.38	74	23	3	1.4
	B-15	7.5	0.86	73	27	0	1.6
	C-87	8.6	0.61	92	8	0	1.6
Silt Loam	A-19	7.8	3.59	43	44	13	1.2
	B-15	8.0	1.64	42	42	16	1.5
	C-45	8.6	0.61	40	49	11	1.7

2.4 Soil Packing

Soils were rebuilt in the lysimeters as close as possible to the original field density by adding the soil in layers of about 7 cm. All lysimeters were saturated with water from bottom to remove air pockets and then gravity drained. These lysimeters were then placed in the trailer for about six months to allow complete soil setting before experimentation.

2.5 Orchard Grass Establishment

Frode variety orchard grass seedlings were transplanted in lysimeters in May 1973. Thirteen plants were established in each lysimeter.

2.6 Sludges Applied

Anaerobic digested, alum treated sludge from Point Edward, ferric chloride treated sludge from North Toronto and lime treated sludge from Newmarket were used for this study. Three annual sludge application rates based on TKN content were applied on established grass in three equal installments (June 5, July 26 and September 5, 1973). The commercial fertilizer treatment at an annual rate of 336 Kg/ha nitrogen, 112 Kg/ha phosphorus and 112 Kg/ha potassium was also applied in three equal installments on the same days.

Equivalent amounts of the other nutrients and metals applied to the grass are summarized in Tables 2 and 3, respectively.

TABLE 2. EQUIVALENT AMOUNTS OF NUTRIENTS AND PETROLEUM HYDROCARBONS APPLIED AT THE RATE OF 900 Kg TKN/ha/ year

CONSTITUENTS		SLUDGES		
		Alum	Iron	Lime
NH_3-N	Kg/ha	219	102	231
Total-P	Kg/ha	1008	411	411
Potassium	Kg/ha	21	84	270
Calcium	Kg/ha	1152	1851	21372
Pet. Hydrocarbon	Kg/ha	6450	213	465
Sludge (Wet)	m^3/ha	852	408	1068
Sludge (Solids)	t/ha	39	29	90

TABLE 3. EQUIVALENT AMOUNTS OF METALS APPLIED AT THE RATE OF 900 Kg TKN/ha/year

CONSTITUENTS		SLUDGES		
		Alum	Iron	Lime
Iron	Kg/ha	315	2262	774
Aluminum	Kg/ha	2973	714	267
Nickel	Kg/ha	1.2	0.4	2.1
Copper	Kg/ha	21	9	15
Zinc	Kg/ha	33	15	6
Sludge (Wet)	m^3/ha	852	408	1068
Sludge (Solids)	t/ha	39	29	90
Zinc Equivalent		4.5	1.8	2.7

2.7 Plant Analysis

During the growing period (May-November, 1972) the orchard grass was harvested on June 26, July 23, August 31 and November 5, 1973. All forage was oven dried, ground in a Wiley mill, screened through a 60 mesh steel screen and analyzed for different elemental contents using standard soil testing and plant analysis procedures (Walsh, 1973).

2.8 Leachate Collection

Leachates of all treatments were collected from the bottom of lysimeters every month and analyzed for elemental concentrations and microbial content using Standard Methods (1971).

2.9 Soil Tests

Soil cores were taken in April 1974 from all eleven treatments of the two soil systems. Samples were taken at 2.5, 7.5, 15, 25, 37.5 and 60 cm depths for bacterial movement investigations. Chemical analyses of soils were performed on the 0-15 cm depth sample only, using standard methods of soil analysis (Black, 1965).

3 RESULTS AND DISCUSSION

3.1 Equivalent Amounts of Elements Applied

It should be noted from Tables 2 and 3 that the three sludges supplied different amounts of the other nutrients, petroleum hydrocarbons and metals. Although the response to rates of sludge nitrogen will be most apparent in plant growth, it cannot be ignored that the highly variable sludge composition will also affect the properties of leachate and soils.

At the maximum annual sludge application rate, alum sludge supplied 6,450 Kg/ha of petroleum hydrocarbons as compared to 465 Kg/ha from lime sludge and 213 Kg/ha from iron sludge. At this application rate, petroleum hydrocarbons could physically suppress the plant growth. Table 2 also shows the wide differences in supplied potassium. The lime sludge supplied 270 Kg/ha as compared to 84 and 21 Kg/ha of potassium from iron and alum sludges, respectively. Sludged soils have been found deficient in potassium (Bear & Prince, 1955; Chawla, 1974). It is

possible that alum sludge treatments already very low in K as compared to other sludge treatments may retard plant growth and could comparatively give lower yields.

Application of 90 tons/ha/year of sludge solids from lime sludge as opposed to 39 and 29 tons/ha/year from alum and iron sludges respectively may pose varied environmental stress to soil and plant systems. It therefore complicates the criteria of sludge application based on a single parameter. Possibly, a combination of several consistent parameters may give a relatively stable index of normal sludge application rate.

Perusal of Table 3 showed that annual applications of alum, iron and lime sludges @ 900 Kg TKN/ha supplied much higher amounts of aluminum (2973 Kg/ha) and iron (2262 Kg/ha) from alum and iron sludges, respectively. These high concentrations may induce plant and soil toxicities much faster and simultaneously, may cause essential plant nutrient deficiencies due to their competing influences in a complex soil plant relationship.

It is also evident from Table 3 that somewhat high amounts of copper (21 Kg/ha) and zinc (33 Kg/ha) were supplied from alum sludge as compared to other sludges. Nickel was only 1.2 Kg/ha. To predict the accumulative toxicity effects of nickel, copper and zinc, zinc equivalent (Webber, 1972) values were calculated for all three sludges at the annual rate of application of 900 Kg TKN/ha. The zinc equivalent value of 4.5 from alum sludge as compared to 2.7 from lime and 1.8 from iron sludge further indicated the higher magnitude of potential toxicity from alum sludge.

3.2 Total Dry Matter Yield of Orchard Grass

During the growing period (May-November, 1973) orchard grass was harvested four times (June 26, July 23, August 31 and November 5, 1973). The dry matter yields (Table 4) obtained from unsludged silt loam (8.4 t/ha) were almost twice that of loamy sand (4.3 t/ha). Commerical fertilizer treatment produced higher dry matter yield (13.2 t/ha) on silt loam as compared to that of loamy sand (10.9) t/ha). The

TABLE 4. TOTAL DRY MATTER YIELD (SUM OF 4 CUTS) OF ORCHARD GRASS MAY-NOVEMBER 1973 (t/ha)

RATES Kg/Ha	LOAMY SAND			SILT LOAM		
	SLUDGES			SLUDGES		
	Alum	Iron	Lime	Alum	Iron	Lime
Control	4.3	4.3	4.3	8.4	8.4	8.4
N-336, P-112, K-112	10.9	10.9	10.9	13.2	13.2	13.2
300 TKN	5.1	7.1	6.2	8.8	11.2	11.1
600 TKN	5.8	8.8	8.6	9.6	12.6	12.7
900 TKN	7.1	11.6	10.6	10.2	15.2	14.4

highest rates of iron and lime sludges on loamy sand produced yields comparable to fertilizer treatments; on silt loam, the yields were relatively higher. Alum sludge at equivalent rates of application gave much lower results than iron sludge, lime sludge and fertilizer treatment, both on loamy sand and silt loam soils. The comparatively low yields of alum sludge treatments may be due to high concentrations of petroleum hydrocarbons resulting in a plant growth supression. Other possilbe causes could be the high zinc equivalent, high contents of aluminum and very low concentrations of potassium.

All three rates of sludge application (300, 600, 900 TKN/ha/yr) from three sludges proportionately increased the dry matter yields on both soils. The corresponding magnitudes of increases were highest from iron sludge, followed by lime sludge and lowest from alum sludge. Irrespective of sludges, nitrogen utilization response as compared to controls was highest on loamy sand than on silt loam. Yields of individual cuts from all the eleven treatments on both soils are shown in Figure 1.

3.3 Mean Concentrations of N, P and K in Orchard Grass

Mean concentrations of nutrients in the orchard grass for the control and seven treatments are presented in Table 5 for comparison purposes.

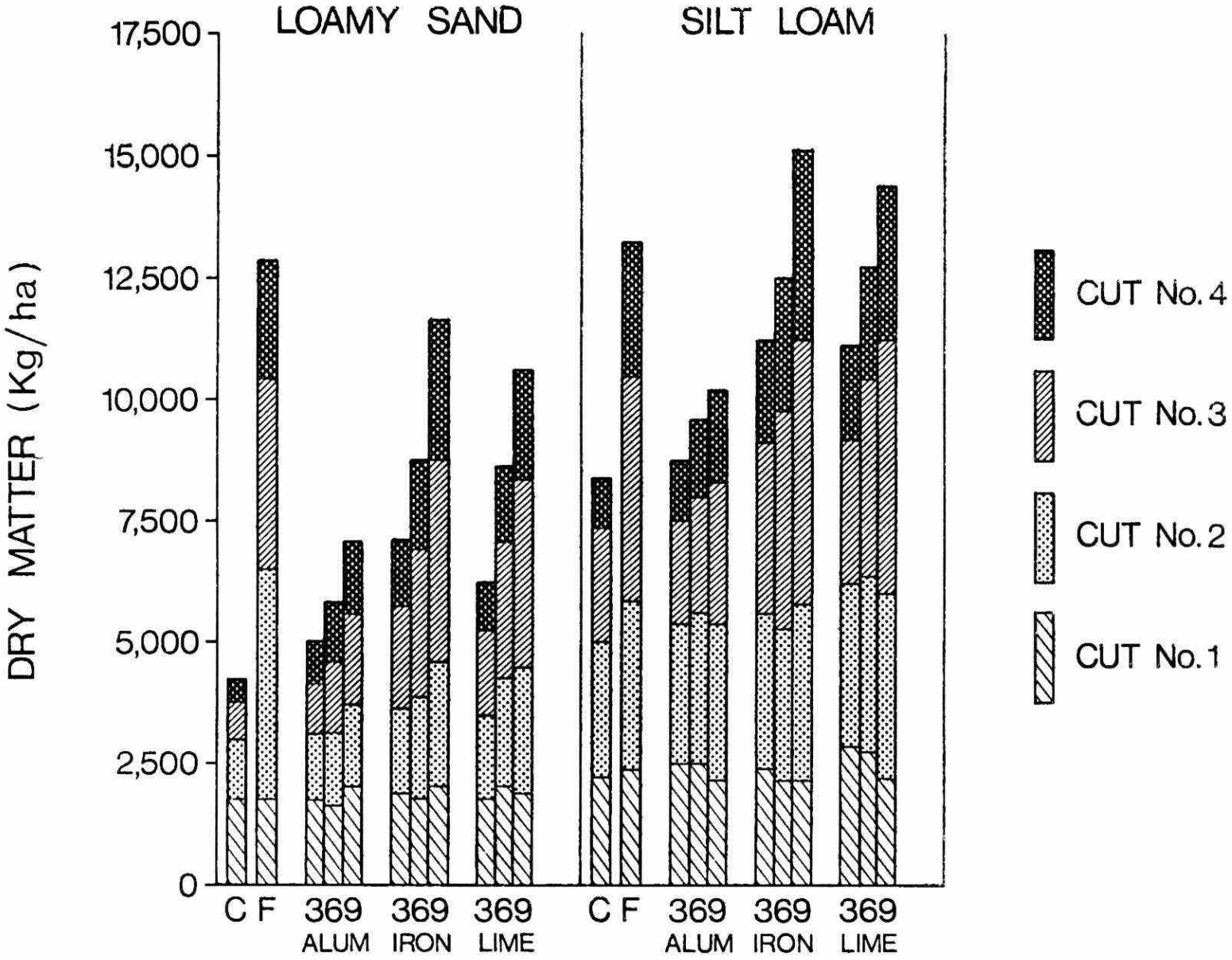

FIG. / YIELD OF ORCHARD GRASS (1973)

TABLE 5. MEAN CONCENTRATIONS OF NUTRIENTS (%) IN ORCHARD GRASS (1973)

TREATMENTS - Kg/ha	LOAMY SAND			SILT LOAM		
	N	P	K	N	P	K
Control	1.98	0.19	2.36	2.36	0.17	3.10
N-336, P-112, K-112	2.63	0.18	2.22	2.76	0.17	2.98
Alum Sludge - 300 TKN	2.01	0.25	2.34	2.27	0.21	3.07
Alum Sludge - 900 TKN	2.21	0.22	2.21	2.44	0.20	3.05
Iron Sludge - 300 TKN	2.10	0.19	2.23	2.41	0.22	3.04
Iron Sludge - 900 TKN	2.69	0.21	1.88	2.77	0.02	2.82
Lime Sludge - 300 TKN	2.38	0.25	2.19	2.47	0.23	2.95
Lime Sludge - 900 TKN	2.71	0.22	1.75	2.82	0.24	2.55

3.3.1 Nitrogen Concentrations

With the exception of alum sludge, the highest rate of sludge application (900 Kg TKN/ha) gave nitrogen concentrations similar to fertilizer treatment. Slightly higher levels of nitrogen were evident (Table 5) on silt loam as compared to loamy sand. The lowest sludge application rates (300 Kg TKN/ha) gave nitrogen values comparable to controls of loamy sand and silt loam with slightly higher concentrations from lime than alum sludge.

The overall mean concentrations of nitrogen from different treatments were, in decreasing order, lime sludges, iron sludges, fertilizer controls and alum sludges. This indicates a possible nitrogen uptake depression under alum sludge treatments. The values of nitrogen ranged from 1.98 to 2.82%.

3.3.2 Phosphorus Concentrations

The overall mean concentrations of phosphorus did not show any trends for the different sludges and application rates. Fertilized and control treatments gave slightly lower concentrations than sludge treatments on both soils. Phosphorus concentrations raged from 0.17 to 0.25 percent.

3.3.3 Potassium Concentrations

The potassium content of plant tissues decreased with the increasing rates of application of all three sludges. The highest rate application (900 Kg TKN/ha) from lime sludge on both soils gave the lowest values of potassium. The higest concentrations were observed from the control system. Potassium concentrations were inversely proportional to nitrogen concentration (Table 5).

The higher rates of TKN fertilization accentuated a potassium deficiency, presumably due to excess potassium uptakes by crop. Such trends were also observed by Griffith et al (1964) in their study of influence of nitrogen and potassium on the yield and chemical composition of orchard grass.

3.4 Total Uptakes of N, P and K in Orchard Grass

The uptakes of total nitrogen, phosphorus and potassium by the orchard glass for the growing period of May-November, 1973 are summarized in Table 6.

3.4.1 Nitrogen Uptake

As expected, the highest uptakes of nitrogen were observed from the highest sludge application rates for both soils. They were directly proportional to the total dry matter produced. Iron sludge removed the highest amount of nitrogen. Net utilization of nitrogen was higher on loamy sand than on silt loam (Table 6).

3.4.2 Phosphorus Uptake

Phosphorus uptake trends were similar to nitrogen except that lime sludge removed greater phosphorus than the other two sludges. This

may possibly be due to the slightly higher availability of phosphorus from calcium phosphate compounds as compared to iron and aluminum phosphate compounds.

TABLE 6. TOTAL UPTAKE OF NUTRIENTS (Kg/ha) BY ORCHARD GRASS (1973)

	LOAMY SAND			SILT LOAM		
TREATMENTS - Kg/ha	N	P	K	N	P	K
Control	87	7	107	202	13	265
N-336, P-112, K-112	276	20	231	357	23	387
Alum Sludge - 300 TKN	105	11	121	202	16	282
Alum Sludge - 900 TKN	157	15	159	243	19	312
Iron Sludge - 300 TKN	147	13	160	268	22	344
Iron Sludge - 900 TKN	300	25	200	400	32	396
Lime Sludge - 300 TKN	146	14	139	278	24	335
Lime Sludge - 900 TKN	273	25	173	390	36	349

3.4.3 Potassium Uptake

The potassium uptakes on the two soils were similar to the nitrogen uptakes. Total uptakes were a direct result of the total yields obtained. Unlike nitrogen and phosphorus, the removals from the highest rates were not significantly higher when compared to the lowest rates of application.

3.5 Mean Concentration of Metals in Orchard Grass

Mean concentrations of metals in plant tissues are summarized in Table 7. High concentrations of aluminum were observed on loamy sand from alum sludge treatment. Iron sludge produced higher aluminum concentrations than the alum sludge on silt loam. Lime sludge treatments resulted in quite low concentrations of aluminum on both soils.

Nickel, copper and zinc concentrations were low under all treatments. However, slightly higher concentrations of copper and zinc under iron sludge were observed.

TABLE 7. MEAN CONCENTRATIONS OF METALS (µg/g) IN ORCHARD GRASS (1973)

TREATMENTS - Kg/ha	LOAMY SAND				SILT LOAM			
	Al	Ni	Cu	Zn	Al	Ni	Cu	Zn
Control	185	1.3	6	41	144	1.5	6	36
N-336, P-112, K-112	117	1.0	7	43	81	1.4	7	42
Alum Sludge - 300 TKN	308	1.4	7	41	138	1.4	6	38
Alum Sludge - 900 TKN	567	1.5	8	44	195	1.3	7	46
Iron Sludge - 300 TKN	122	1.0	8	52	288	1.6	13	54
Iron Sludge - 900 TKN	114	1.5	10	59	219	1.3	10	54
Lime Sludge - 300 TKN	79	1.2	6	44	80	1.4	7	41
Lime Sludge - 900 TKN	83	1.2	7	49	71	1.3	7	44

3.6 Total Uptake of Metals by Orchard Grass

Aluminum, nickel, copper and zinc uptakes of plants are given in Table 8.

The highest amounts of aluminum were removed at the highest alum sludge application rate on loamy sand (3.7 Kg/ha).

The uptakes of nickel, copper and zinc were proportional to rates of sludging and the amounts removed were a direct result of the yields of dry matter obtained. None of these metals was removed more than one Kg/ha/yr under any treatment for either soil (Table 8). All these metal removals are much lower than the amount of metals added (Table 3). Metal accumulations of high magnitude will result in the soil system.

TABLE 8. TOTAL UPTAKE OF METALS (g/ha) BY ORCHARD GRASS (1973)

TREATMENTS - Kg/ha	LOAMY SAND				SILT LOAM			
	Al	Ni	Cu	Zn	Al	Ni	Cu	Zn
Control	550	5	29	178	910	13	58	301
N-336, P-112, K-112	1225	11	70	452	1010	18	96	549
Alum Sludge - 300 TKN	1275	7	35	211	1010	12	60	337
Alum Sludge - 900 TKN	3735	10	58	311	1730	14	72	462
Iron Sludge - 300 TKN	820	7	57	359	2700	18	141	564
Iron Sludge - 900 TKN	1930	17	113	669	2210	19	139	807
Lime Sludge - 300 TKN	435	6	39	262	790	16	79	444
Lime Sludge - 900 TKN	825	13	65	500	1040	17	93	626

3.7 Mean Concentrations of Nutrients in Leachate

Samples of leachate were collected every month from all treatments over the entire period of study (May 1973 - April 1974). The leachates were analyzed for soluble and total nutrients, minerals and metals. The nutrient results are summarized in Table 9.

Total nitrogen concentrations were greater under higher rates of sludge application, but the differences among sludges were non-significant. Comparatively higher concentrations were leached from loamy sand. Organic carbon concentrations were about the same among sludges at all rates. Somewhat higher concentrations were evident from silt loam. Calcium leaching trends were similar to organic carbon. These concentrations cannot be considered environmentally hazardous.

3.8 Mean Concentrations of Metals in Leachate

Overall mean concentrations of aluminum, nickel, copper and zinc in the leachate are shown in Table 10. Unlike nitrogen, concentrations of Al, Ni, Cu and Zn were slightly higher from silt loam as compared to loamy

TABLE 9. MEAN CONCENTRATIONS OF NUTRIENTS (mg/1) IN LEACHATE FROM MAY 1973 - APRIL 1974

TREATMENTS - Kg/ha	LOAMY SAND			SILT LOAM		
	Total-N	Org. C	Ca	Total-N	Org. C	Ca
Control	15	6	75	4	9	90
N-336, P-112, K-112	21	7	75	13	9	76
Alum Sludge - 300 TKN	14	7	88	8	8	96
Alum Sludge - 900 TKN	20	7	97	12	10	103
Iron Sludge - 300 TKN	16	6	91	10	7	85
Iron Sludge - 900 TKN	25	8	101	10	10	95
Lime Sludge - 300 TKN	19	6	84	9	9	92
Lime Sludge - 900 TKN	18	9	98	14	12	107

TABLE 10. MEAN CONCENTRATIONS OF METALS (µg/1) IN LEACHATE FROM MAY 1973 - APRIL 1974

TREATMENTS - Kg/ha	LOAMY SAND				SILT LOAM			
	Al	Ni	Cu	Zn	Al	Ni	Cu	Zn
Control	20	6	13	7	24	10	24	15
N-336, P-112, K-112	17	7	14	8	27	12	43	30
Alum Sludge - 300 TKN	22	7	10	6	23	12	34	10
Alum Sludge - 900 TKN	15	7	11	6	23	12	34	13
Iron Sludge - 300 TKN	20	6	12	6	20	11	25	11
Iron Sludge - 900 TKN	19	7	13	6	28	15	41	23
Lime Sludge - 300 TKN	19	8	19	11	24	9	27	13
Lime Sludge - 900 TKN	18	7	13	6	29	24	52	21

sand. All the concentrations were low and did not reveal any significant trend due to increasing rates of application or among sludges. Such low concentrations of heavy metals in drainage water could not be considered dangerous to ground water supplies.

3.9 Total Removals of N, P and K from the Soil System

Figures 2, 3 and 4 show the total removals of nitrogen, phosphorus and potassium respectively. On loamy sand the majority of the nitrogen is removed through plant uptakes with a significant contribution through leachate losses. On silt loam almost all the removal was through plant uptake.

Phosphorus (Figure 3) and potassium (Figure 4) removals were entirely through plant uptakes with nonsignificant contributions through leachate. Highest removals of P and K were observed on silt loam soil as compared to sandy loam.

3.10 Total Removal of Cu, Ni and Zn from the Soil System

Figures 5, 6 and 7 show the removals of copper, nickel and zinc, respectively. Although relatively small amounts of copper were removed, it is interesting to note that plant uptake contributions were about the same as that of leaching losses on loamy sand. For silt loam, removals through plant uptakes were comparatively higher than leachings.

The majority of the nickel (Figure 6) and zinc (Figure 7) were removed through plant uptakes with insignificant losses through leachate. Further examination of data indicated that in all cases amounts of copper, nickel and zinc were very low as compared to original amounts added to the soil system (Table 3).

3.11 Effect of Sludge Addition on Soils

Soil samples were taken in April 1974 to investigate changes in the soil systems. Table 11 summarizes some selective tests made.

When compared to the control system, tests positively indicate an increase in the nitrogen content of both the soil types at all application rates. Concentrations of potassium and organic matter do not show clear trends for the different sludges at different application rates. It is obvious that pH values under highest rates of alum sludge and under both rates of iron sludge have dropped down as compared to control, fertilizer

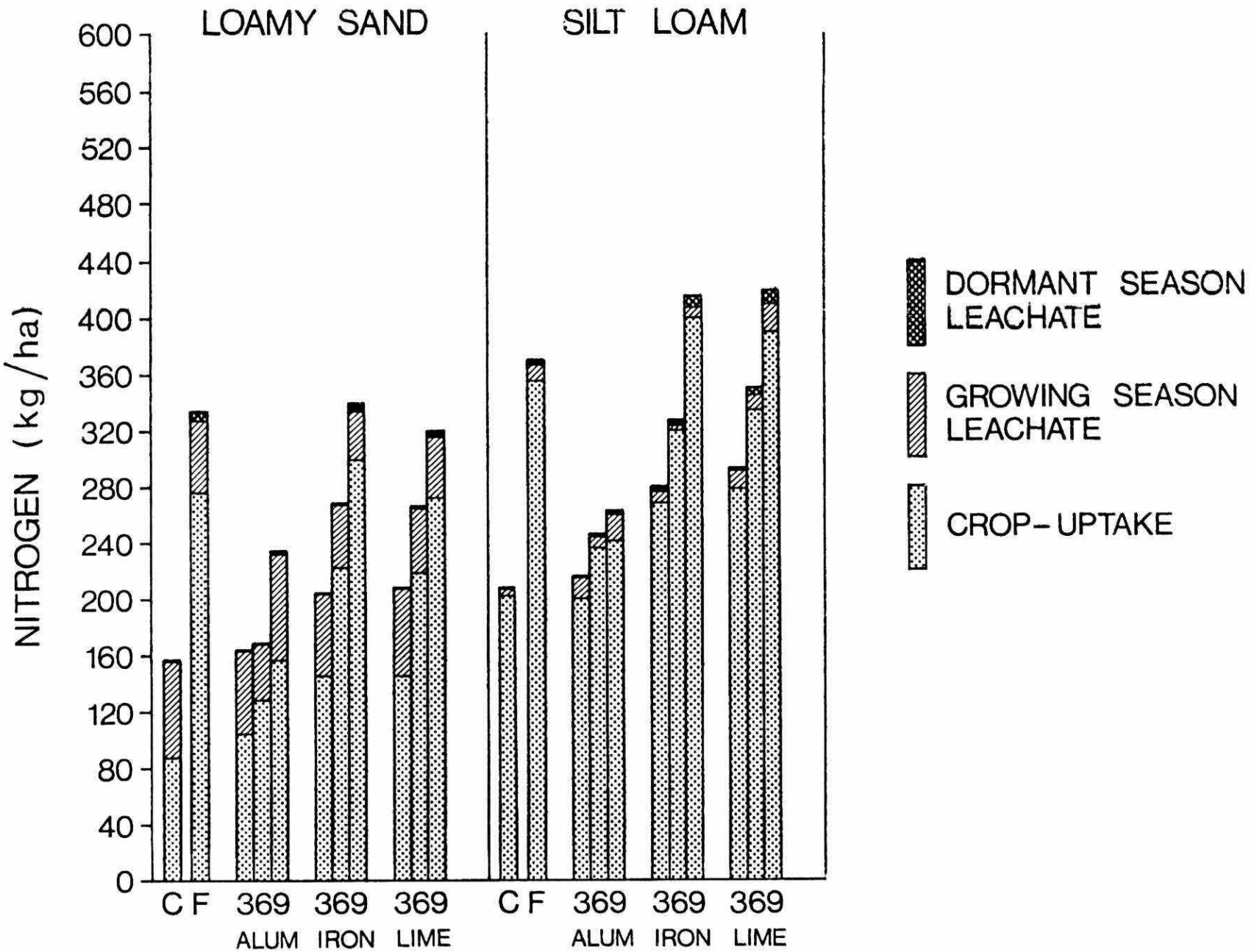

FIG. 2 TOTAL NITROGEN REMOVED (MAY 1973 TO APRIL 1974)

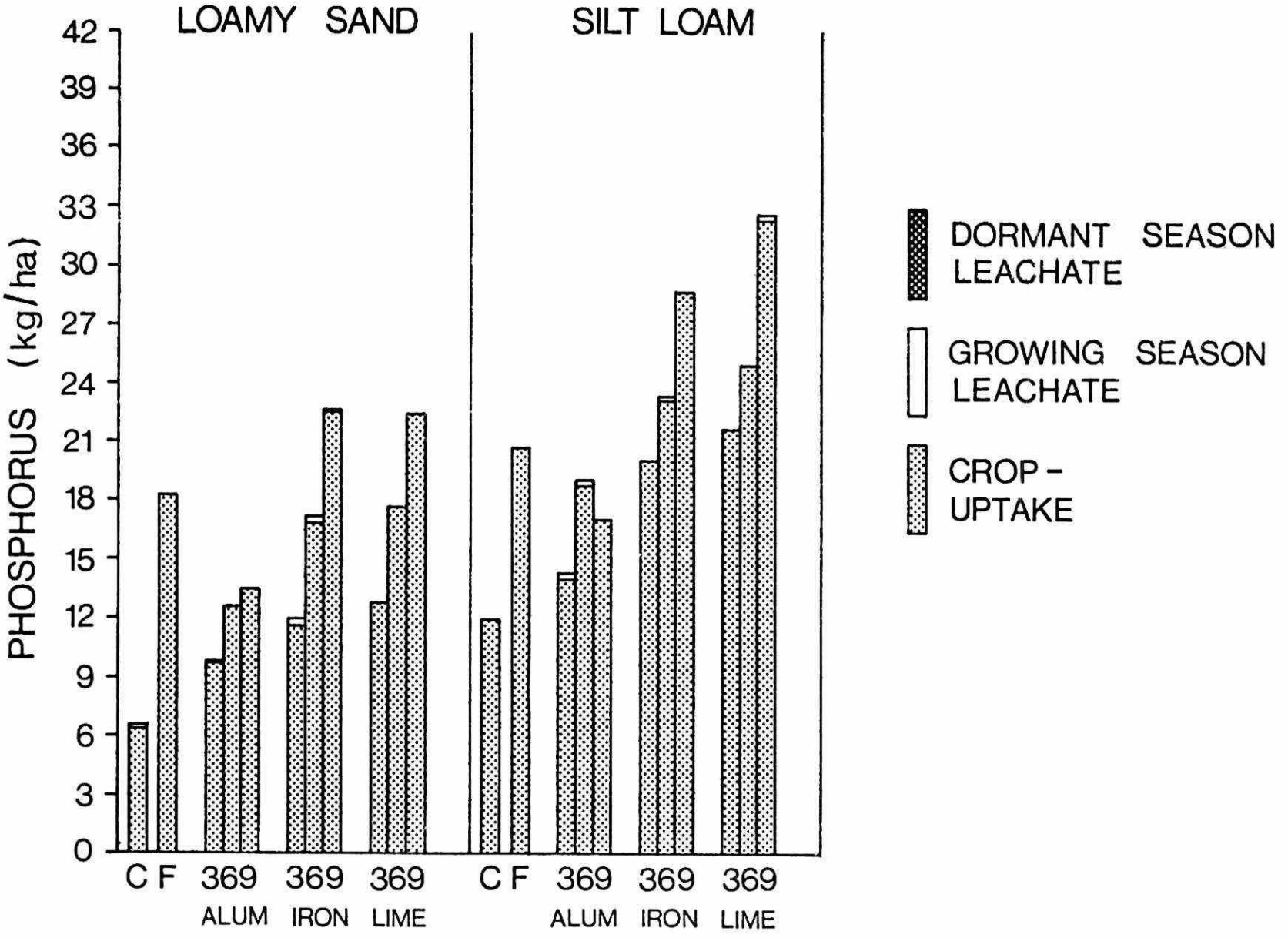

FIG. 3 TOTAL PHOSPHORUS REMOVED (MAY 1973 TO APR. 1974)

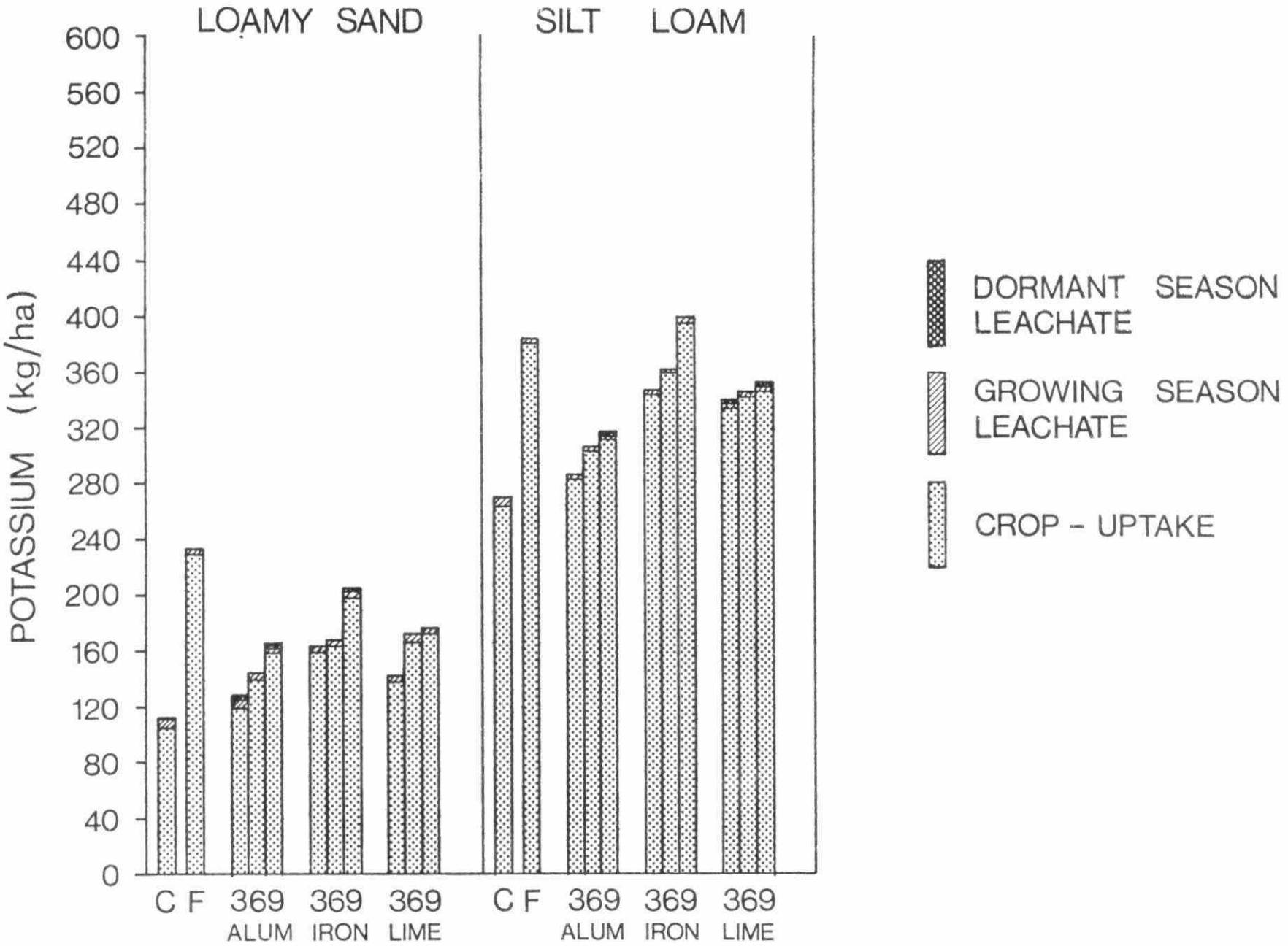

FIG. 4 TOTAL POTASSIUM REMOVED (MAY 1973 TO APR. 1974)

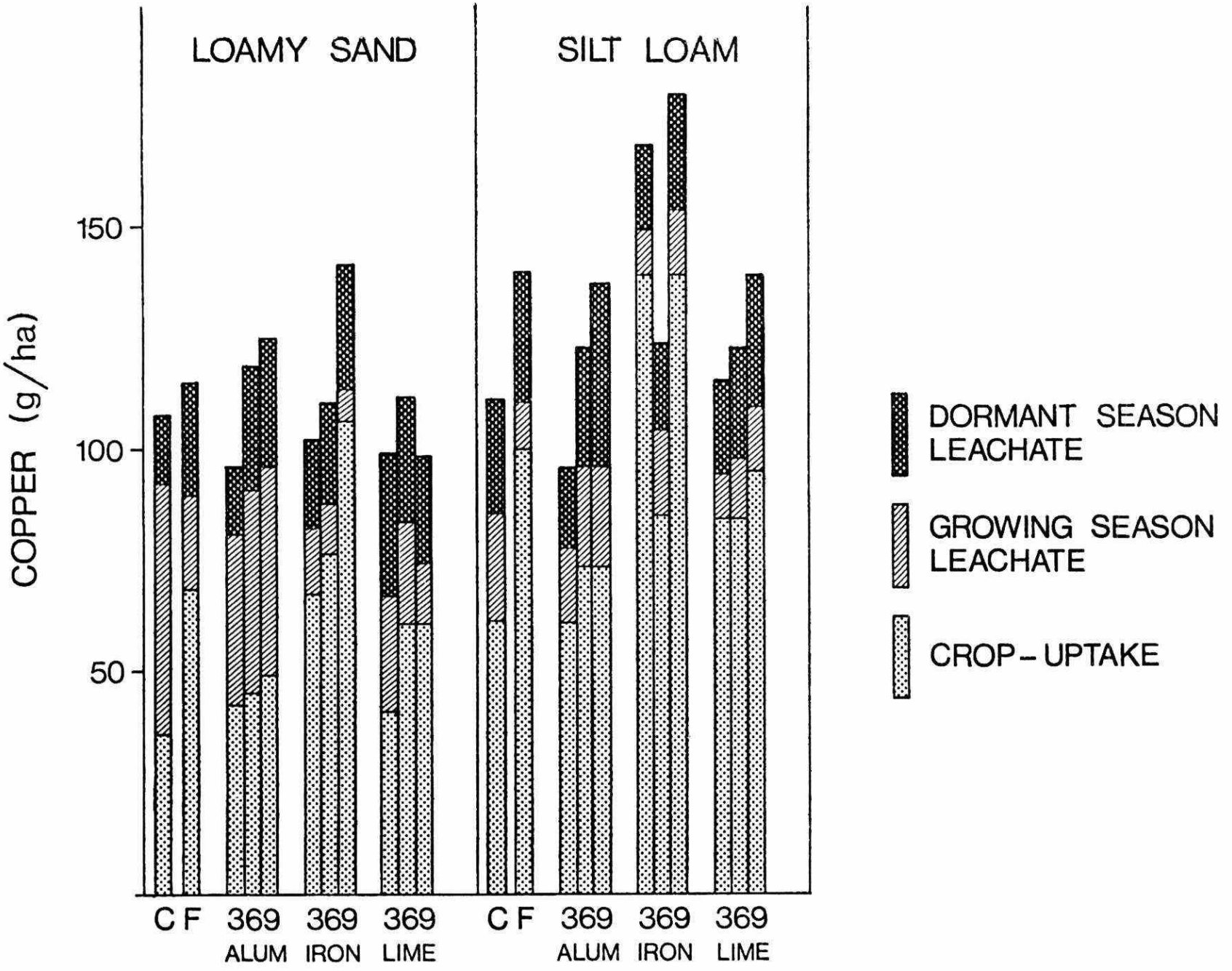

FIG. 5 TOTAL COPPER REMOVED (MAY 1973 TO APRIL 1974)

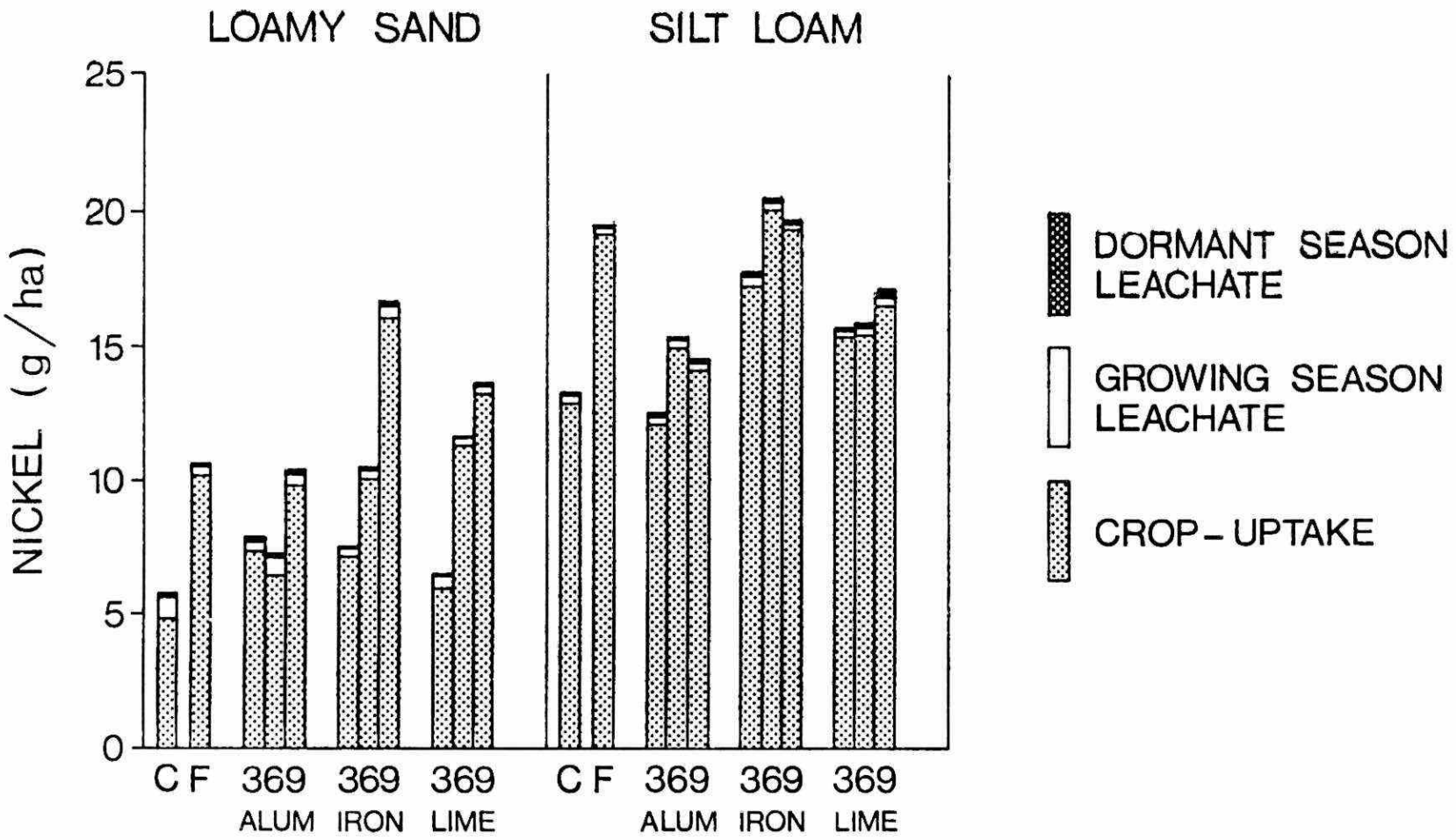

FIG. 6 TOTAL NICKEL REMOVED (MAY 1973 TO APRIL 1974)

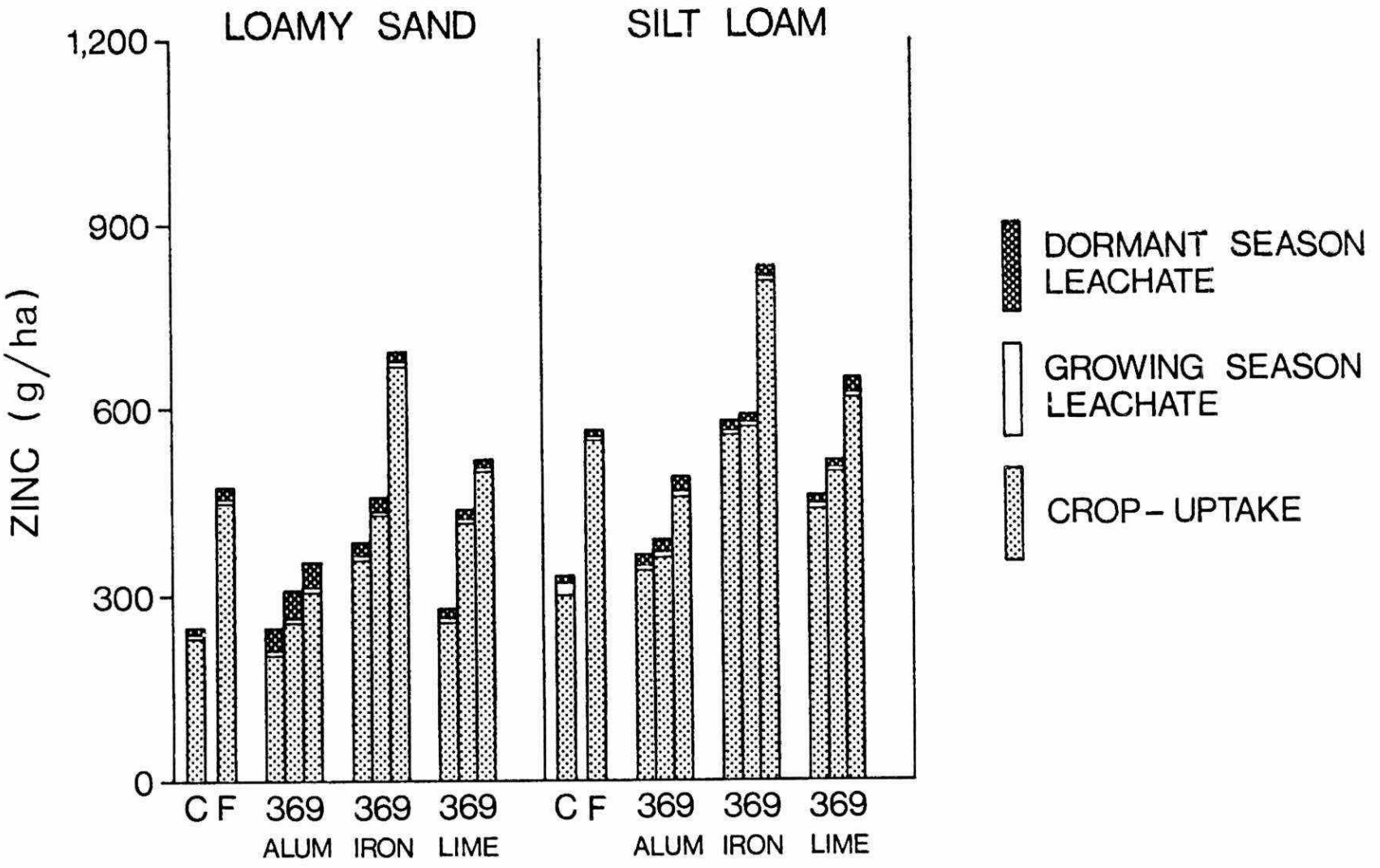

FIG 7 TOTAL ZINC REMOVED (MAY 1973 TO APRIL 1974)

and lime sludge treatments. This possibly due to higher rate of mineralization under iron sludge. This further suggests that unlimed sludged soils may create acidity, resulting in metallic toxicity to plants.

TABLE 11. VALUES OF NUTRIENTS AND pH IN SOILS (0-15 cm) AFTER ONE YEAR OF SLUDGING (APRIL 1974)

TREATMENTS - Kg/ha	LOAMY SAND				SILT LOAM			
	Organic Matter %	TKN (µg/g)	K (µg/g)	pH	Organic Matter	TKN (µg/g)	K (µg/g)	pH
Control	2.17	770	15.8	7.8	3.14	1610	16.8	7.7
N-336, P-112, K-112	2.06	700	15.6	7.8	3.16	1750	18.8	8.0
Alum Sludge - 300 TKN	2.05	1050	16.5	7.6	3.27	1960	16.5	7.9
Alum Sludge - 900 TKN	2.53	1120	15.0	6.6	3.34	2170	21.0	6.8
Iron Sludge - 300 TKN	2.01	1120	16.5	6.6	3.12	2030	17.3	6.8
Iron Sludge - 900 TKN	1.96	1260	15.0	6.5	3.28	2100	21.0	6.6
Lime Sludge - 300 TKN	1.75	1050	14.3	7.4	3.02	1890	18.8	7.4
Lime Sludge - 900 TKN	2.05	1260	15.0	7.6	2.94	2100	20.3	7.6

3.12 Movement of Heterotrophic Bacteria in Sludged Soils

Coliform bacteria have been traditionally used as the indicator bacteria for the study of movement of sludge bacteria in soils (Krone, 1968). Coliform bacteria are not the predominant bacteria in digested sludges; at best they account for only 0.1% of the total population of sludge bacteria (Chawla et al, 1974). In the present study, heterotrophic bacteria have been used as the indicator of sludge bacteria movement in the soil system.

Soil samples taken one year after sludge application to the silt loam soil at 900 Kg TKN/ha from alum, iron and lime sludges were analyzed for the total heterotrophic bacteria population. Soil depths monitored were 2.5, 7.5, .5, 25, 37.5, and 60 cm. Densities of bacteria at different depths are shown in Figure 8. It is evident from the illustration that a linear decrease of bacteria existed in the first 15 cm layer of soil. After 15 cm soil depth, the bacterial population gradually declined proportional to depth.

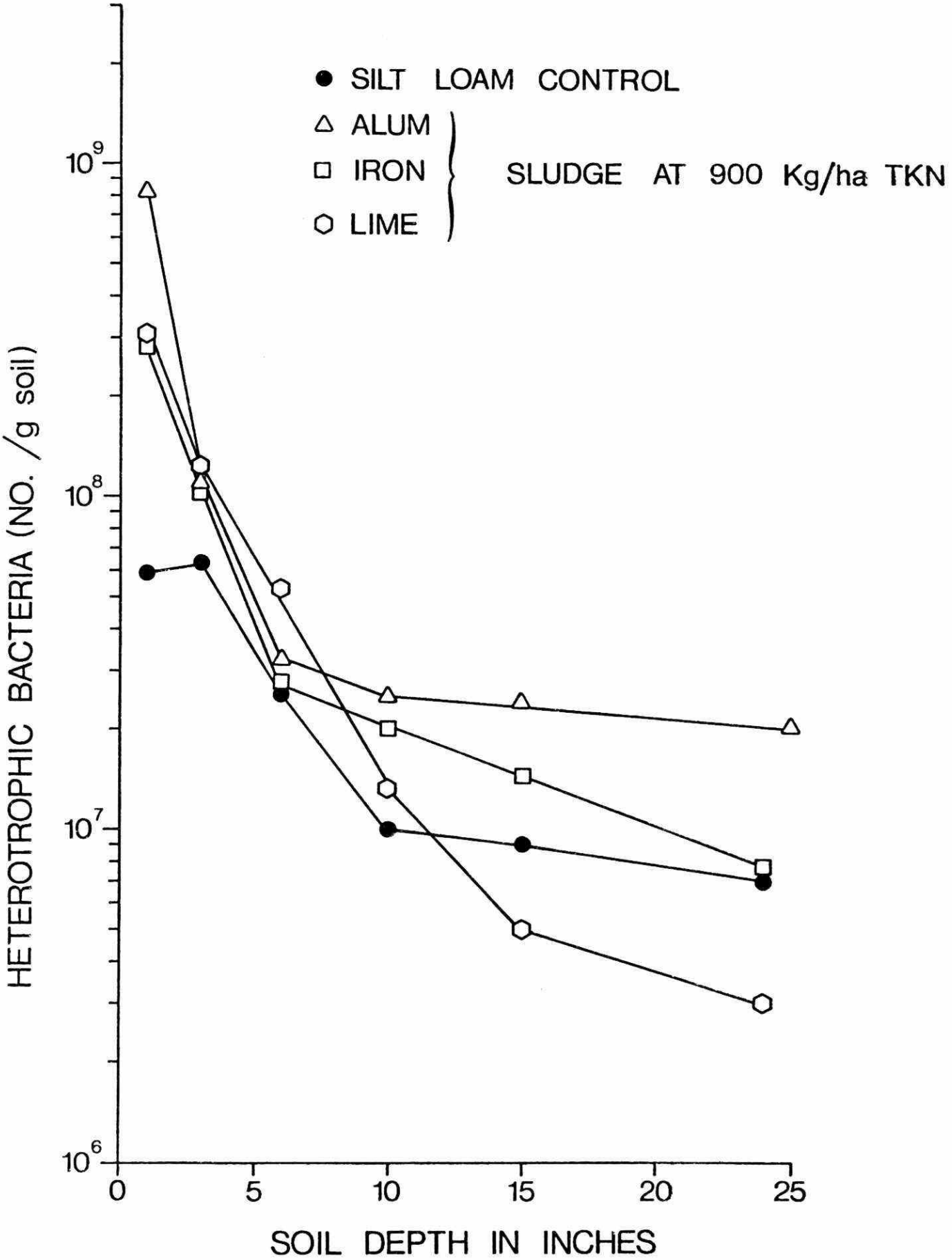

FIG. 8 TOTAL HETEROTROPHIC BACTERIA IN SOIL (APR. 1974)

Further examination of the data (Figure 8) indicated that 95% of heterotrophic bacteria were still in the top 15 cm layer of soil.

3 SUMMARY AND CONCLUSIONS

Extensive lysimeter investigations are underway at the Wastewater Technology Centre, Burlington, to study the long-range environmental effects of chemical sewage sludge disposal on land. Digested alum, iron and lime sludges from Point Edward, North Toronto and Newmarket were applied onto established orchard grass at annual rates of 300, 600 and 900 Kg TKN/ha. Two soil systems used for the studies were loamy sand from Cambridge and silt loam from Guelph.

The following conclusions have been reached:

1. One year of studies are inadequate to predict long-range environmental effects on a complex sludge-soil-plant system.
2. Increasing rates of sludge application (up to 900 Kg/ha nitrogen) resulted in an increased yield of total dry matter. The highest rates of iron and lime sludges on loamy sand produced yields comparable to fertilizer treatments; on silt loam the yields were higher than with commercial fertilizer addition. Alum sludge at equivalent rates of application gave much lower results than iron sludge, lime sludge and fertilizer treatments both on loamy sand and silt loam soils.
3. Cumulative effects of higher zinc equivalent, higher aluminum contents and low potassium amounts in alum sludges might have retarded the plant growth. Very high concentrations of petroleum hydrocarbons in the alum sludge possibly caused some plant toxicity resulting in lower yields.
4. Increasing the rates of sludge application increased the nitrogen content of the plants; phosphorus did not show any meaningful trend; potassium contents decreased with increasing rates of sludge addition. Nickel, copper and zinc concentrations in plant tissues were reasonably low and similar to the control and fertilizer treatments.

5. Concentrations of nitrogen in the leachate were higher at the highest rates of application, but differences among sludges were insignificant. Overall levels of total nitrogen in the leachate were not considered as potentially hazardous to groundwater supplies.
6. Total removals of nitrogen, phosphorus and potassium from the sludged soil system were mostly through plant uptakes and some contributions of nitrogen through leachings also occurred. Mostly copper, nickel and zinc removals were from plant uptakes. A portion of the total removal for copper was due to the leachate lost. However, total removals were insignificant when compared to the quantities added with the sludges.
7. One year after sludging, no definite chemical changes in the soil systems were observed. Decline in pH values under highest rates of iron and alum sludges suggest a trend toward increased mineralization and acidification due to a lack of calcium.
8. A profile of heterotrophic bacterial densities indicated an entrapment of sludge bacteria in the upper 15 cm layer of soil systems.

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ANALYSIS OF HEAVY METALS IN SEWAGE SLUDGE AND LIQUIDS ASSOCIATED WITH SLUDGES

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INTRODUCTION

Several authors have recorded the heavy metal content of sewage sludge, e.g. Abbott (1971), Anderson (1956), Berrow and Webber (1972), Oden et al (1970), Rehling and Troug (1939), Van Loon and Lichwa (1973), and Webber (1972). Results indicate very high levels of metals compared to soils and stream sediments. Unfortunately in most cases, little detail of the analytical method has been given. Standard reference materials in most cases were were not analyzed. Hence an assessment of the validity of the data is impossible.

EXPERIMENTAL

A. Equipment

An instrumentation Laboratories Model 153 equipped with a high solids burner was used for acid extracted sludge sample. The same instrument with a Boling 3 slot burner was used for solvent extracted metal water samples. A Perkin Elmer 303 equipped with an HGA 70 Graphite furnace was used for metal volatility studies and for metal determination directly in water samples.

Mercury analyses were done with the Coleman MSA 50 Analyzer and the IL 153 AAS unit modified with a cold vapour tube. Use deuterium arc background correction.

B. Reagents and Solutions

A 1% aqueous solution of ammonium pyrolidine dithiocarbonate (APDC) was prepared and extracted twice with methyl isobutyl ketone (MIBK). This solution was prepared fresh weekly.

A buffer solution was made by mixing 570 ml glacial acetic acid and 82 g sodium acetate and then diluting to 1l with water.

All acids and chemicals used were reagent grade. Fisher Certified. Blanks were run at all times to eliminate problems from contamination.

Standard aqueous metal solutions (1000 ppm metal) were prepared from reagent grade metals or metal salts. Working solutions were prepared by diluting the above by an appropriate amount being careful to maintain an acidity (HNO_3) of approximately 5% by volume.

C. Reference Standards

Perhaps the most important point for emphasis is the need to use reference standard materials as a method of self-evaluation during routine analytical determinations. Unfortunately no totally satisfactory standards covering the compositional range of the samples in question exist. Thus the approach taken in this study was to utilize standards which have some of the properties of these samples and to develop internal laboratory standards in comparison with performance on the chosen standards.

The standards chosen were National Bureau of Standards Orchard Leaves, SRM 1571, Bovine Liver, SRM 1577 and the Environmental Protection Agency Trace Metal Water Samples.

D. Analysis of Solid Products

Procedure for Cd, Cr, Pb, Ni, Zn, Mn, Cu, Fe, Mn, Al and V:

Sampling: No firm guidelines on sampling are possible. The worker must be cautioned that failure to fully investigate sampling constraints may invalidate the data. Problems encountered in the author's experience are discussed below.

Procedure: Weigh 0.5 g of a "representative sample" into an acid washed (aqua regia) 100 ml beaker. Add 9 ml HCL and 3 ml HNO_3. Heat on medium heat for 1 hour. (During this time samples evaporate to near dryness.) If any are dry add 1 ml nitric acid. Dilute to 10 ml with water and filter (Whatman #42) into a 25 ml flask. Wash the filter well with water and dilute to volume.

For sludge and sludge based fertilizer samples the following dilutions are commonly needed. Dilute 2 ml of stock solution to 25, 100 and 250 ml. Dilute 2 ml of the above 25 ml dilution to 250 ml. Make the acid content 5% with HNO_3 in each case.

Run the solutions on the atomic absorption using the conditions outlined in Table 1. Background correction was done using either the lines listed in Table 1 or the deuterium arc corrector when applicable.

TABLE 1

Atomic Absorption Parameters

Element	Analytical line nm	Background line nm	Oxidant	Slit µm
Al	309.2	nn	N_2O	80
V	218.4	319.6	N_2O	80
Cr	357.9	(366)*	air	40
Cd	228.8	226.4	air	80
Pb	283.3	282.0	air	80
Ni	232.0	231.6	air	40
Zn	213.9	(212)	air	80
Cu	324.7	296.1	air	80
Mn	279.5	281.7	air	40
Fe	248.3	nn	air	40

nn - not needed

* Line found suitable for our lamp - accurate wavelength not known.

Standard working solutions were run at the same time to obtain calibration curves. In addition a reference standard, either an internal laboratory standard or an NBS standard, was run with each batch.

Procedure for Ag:

Sampling: See below.

Procedure: For samples which are low in Ag (usually 5 ppm or less) the above aqua regia procedure may be applicable. However, for many samples silver is precipitated during the above procedure as insoluble AgCl. If this occurs the following procedure is recommended.

Weigh 0.5 g of sample into a 100 ml pyrex beaker. Ash the sample at 450°C to a light ash product. Extract the ash over medium heat with 9 ml of HNO_3. Continue as in the above procedure.

Procedure for Hg:

Sampling: See below.

Procedure: Weigh a 0.1 to 10 g sample depending on Hg content, into a BOD bottle supplied with the Coleman MAS 50. Add 15 ml of 7N HNO_3, 15 ml 1.1 H_2SO_4 and 10 ml of 5% of $KMnO_4$ solution. Heat on a low heat, less than 75°C for 15 minutes. During this period add $KMnO_4$ crystals as required to keep a persistant purple colour in the solution. Cool to room temperature and add 10 ml of 0.1% hydroxylamine hydrochloride followed by 10 ml of 10% $SnCl_2$ 2 H_2O solution and run on the Coleman MAS 50 analyzer or IL 153. The above procedure is modified from that recommended by Hatch and Ott (1969) for other sample types. If background absorption is a problem correct using the arc.

E. Procedural Discussion

Sampling: Typical residence times in sludge digester are of the order of 20 days. On this basis it might be expected that a grab sample from the tank would be representative. For the plants studied, this was not the case. Hence it is recommended that a number of grab samples be taken from the tank outlet and then combined into a single sample for analysis. The exact number would be governed by the use of the analysis and the nature of the plant concerned.

The "representative sample" is then filtered through a good grade analytical filter paper. The drained solid is dried at 100°C and the resultant cake ground in a mortar to pass a -120 mesh sieve.

Decomposition Method: Several alternatives for decomposition of sludge samples for elements other than Hg exist:

1. Samples can be ashed at a suitable temperature to remove organic material or the sample could be decomposed directly with acid and risk potential organic matter problems due to organic matter in sample solutions.

2. A variety of acids could be suggested for decomposition. These include HCL, HNO_3, HF, H_2SO_4, $HClO_4$, etc., or a combination of two or more. Choice of the proper acid or combination of acids will be governed by a comprehensive testing program on a wide range of sludge compositions.

In this study a variety of sludges from a representative grouping of treatment plants was subjected to various combinations of the variables given below.

It was found that an aqua regia (HCL and HNO_3) extraction of the unashed sludge gave greater than 90% extraction efficiency for the elements studied except for silver. In this case an ashed sample treated only with HNO_3 gave satisfactory recoveries. Table II gives results obtained for a total decomposition procedure compared to the recommended procedure.

Table II

Total Decomposition Values vs. Acid Extraction in Proposed Procedure - Toronto Sludge

Method	Al	Fe	Cr	Zn	Pb	Cu	Cd	Ni	Mn	V
	%						ppm			
Total	1.2	7.8	0.40	0.60	0.14	0.12	44	190	260	10
Acid	1.1	7.6	0.42	0.58	0.14	0.12	45	165	250	10

When ashing of sludges is desired a temperature of 450°C can be used without fear of loss of all the more volatile metals, e.g. Cd, Zn, except for Hg. This hypothesis was verified by ashing samples directly in the HGA 70, graphite furnace at various temperatures.

Interferences: An extensive study of interference problems associated with the atomic absorption determination was done.

By a careful adjustment of flame conditions, as dictated by individual instruments and burners, conditions could be found which resulted in not appreciable chemical interference for the elements studied. In this regard greatest care is necessary in the determinations of Ni and Cr.

However because of the high salt contents which were present in concentrated sample solutions due to major matrix constituents such as Na, Mg, K, chloride, nitrate, etc., background interference was a serious problem in some determinations. This type of interference can be overcome through the use of the absorbance obtained at a suitable nonabsorbing line. This absorbance is subtracted from the absorbance obtained at the absorbing line. Table 1 has a listing of suitable lines. Some instruments can be purchased which have an automatic background compensation device. While this is useful in many cases, it may fail to give suitable correction when background levels are above 50% of the total signal. Elements analyzed in diluted sample solutions, e.g. Fe, Al, etc., do not suffer from background absorption problems.

F. Analysis of Waters

Procedure - "Extractable" Metals (Cu, Fe, Pb, Ni, Zn, Cd)

Acidify the water to pH = 1 with HNO_3. Place the desired sample (usually 200 ml) in a 250 ml separatory funnel fitted with a teflon stopcock. Add 4 ml of the buffer. Shake to mix well. The pH should be 4.0 ± 0.1. If this is not the case add sufficient 20% NaOH solution to obtain this value. Add 1.5 ml of 1% APDC. Shake briefly. Add 10 to 20 ml (depending on concentration factor required) of MIBK. Shake vigorously for 60 seconds. Allow the layers to separate. Retain the MIBK layer in tightly capped glass bottles until samples have all been made ready for analysis. Prepare standards for multi-element stock solution so that the 200 ml of water extracted contains 4 concentrations within the ranges of Fe 10 to 200 ppb, Cu 5 to 100 ppb, Ni 5 to 100 ppb, Cd 1 to 20 ppb, Zn 10 to 200 ppb, and PB 10 to 2000 ppb. In this way a direct concentration relationship exists with samples. Run a reagent blank.

Procedure - "Total" Metal (Cu, Ni, Fe, Pb, Zn, Hg, Cd)

Add 1 ml of HNO_3 to the desired sample. Evaporate the sample to dryness on medium heat of a hot plate. Add 2 ml of HCl + 1 ml of HNO_3. Evaporate to dryness. Add a drop of HCl and dilute to 200 ml. Continue as for extractable metal above. Run a blank containing acids.

For Hg add 1 ml HNO_3 and 1 ml 5% $KMnO_4$. Heat for 30 min. on

a hot plate at medium heat. Cool. Run by the cold vapor mercury method described above.

G. Procedural Discussion - Metals in Waters

Gibbs (1973) identified 5 mechanisms by which metal can be transported in waters: in solution and organic complexes, adsorbed, precipitated and coprecipitated in organic solids, and in crystalline sediment material. Whether one agrees with such a calssification or not it is obvious that metals in some forms are more available for reaction with biological components of the environment than others. It would be impossible to give a meaningful discussion of metal availability in a paper of this nature, mainly because of the wide range of opinion that exists. In spite of this it is probably useful to distinguish between easily "extractable" metal and "total" metal in waters. "Extractable" metal in this context is that metal, both bound and unbound, which can be extracted by the organic reagents used according to the proposed procedure. "Total" metal refers to that metal which is released by the acid digestion given above. This metal is termed "total" metal because experience with the procedure indicates that over 90% of the metal in the water is released by the proposed method.

Filtration: No general accord exists on the method of water pre-treatment prior to analysis. Most authors agree on an acidification following filtration. The filtration should be done at the time of sample collection or within a few hours thereafter. It is common to filter waters through a 0.45 μ porosity filter. Metal which passes this porosity is often termed "soluble". The present author believes that a significant percentage of particulate metal passes this filter porosity size. Work designed to clarify some of the above variables is in progress in this laboratory, embracing a wide range of water sample types.

RESULTS AND DISCUSSION

A. Precision and Accuracy of Results

1. Solids

No standard sludge samples exist on which to test accuracy. However, the National Bureau of Standards (Washington, D.C.) has available, Standard Orchard Leaves S.R.M. #1571 and Bovine Liver S.R.M. #1577. These samples will give a good indication of the accuracy obtained on samples with an organic matrix. These samples were run during routine laboratory operations and typical results are given in Table III.

TABLE III

NBS Standards (ppm)

St.		Cd	Cr	Pb	Ni	Zn	Cu	Fe	Hg	Mn
1571	NBS	0.1	2.3	45	1.3	25	12	300	0.16	91
	Ours	0.2	2.5	43	1.3	32	9	260	0.12	81
1577	NBS	0.3	na	0.34	na	130	193	270	0.016	10
	Ours	0.3	34	3.5	1.1	131	170	252	na	9

na - not available

To check on repeatability two control sludge samples were chosen and repeated with each set. This will give you some indication of variation within the sample as well as operator repeatability. To try to obtain another measure of operator repeatability a single sample was dissolved and analyzed 5 times using the same sample solution. This would eliminate variation from sample inhomogeneity. Results for these tests are given in Table IV.

TABLE IV

Repeatability

	Cd	Cr	Pb	Ni	Cu	Hg	Mn	Ag	Zn	Fe	Al
	PPM									%	
One sample solution repeated 5 times											
$\bar{x}$	14	550	790	28	860	-	430	49	0.23	7.8	1.3
min	13	530	760	27	850	-	410	48	0.22	7.6	1.3
max	14	560	820	30	900	-	450	50	0.23	7.8	1.3
North Toronto Control, done 18 times											
$\bar{x}$	12	525	790	25	930	21	420	48	0.19	7.7	1.3
min	11	460	680	23	900	19	370	40	0.18	6.0	1.2
max	13	560	880	27	960	28	450	58	0.21	8.2	1.4
Newmarket Control, done 18 times											
$\bar{x}$	2	18	97	5	160	1	220	10	490	0.29	0.10
min	1	13	67	4	130	1	180	9	425	0.24	0.09
max	2	21	137	8	180	1	240	10	540	0.32	0.11

These data suggest a sample inhomogeneity problem. A test was made on several samples of sludges taken at the same time. Analyses of different bottles showed a spread similar to that shown by the control sample. Hence it is doubtful that a grab sludge sample is representative of the sludge in a digester tank.

2. Liquids

The Environmental Protection Agency (Cincinnati, Ohio) provides water sample standards containing heavy metals. These were analyzed during the routine laboratory operation and the results recorded in Table V.

Because of the volumes of samples involved repeatability, as assessed by control sample, could not be obtained. EPA sample 1 was analyzed 3 times and the repeatability was as follows: (ppb) Zn ±1, Fe ±2, Pb ±2, Cu ±0.5 and Cd ±0.2.

B. Metal Composition of Typical Sludges

Samples of sludge from a range of plants were analyzed for metals; the results are given in Table VI. Analyses are for sampling periods of 1 to 12 months.

Toronto is a heavily urbanized area of two million people. Kitchener and Oshawa are medium sized cities in the 100,000 to 200,000 population range. Both cities have a range of specialized industry with the latter being the automobile manufacturing centre of Canada. Newmarket, Aurora, Thornhill and Point Edward receive input from smaller communities of populations less than 50,000. Newmarket is the smallest community and has only a very minimal amount of industry. A random selection of fertilizers available from stores in Toronto was analyzed and the results are given in Table VII.

TABLE V

EPA Water Standards

		ppb						
		Zn	Fe	Pb	Ni	Cu	Cd	Hg
EPA 1	Ours	11	18	31	<1	9	1.5	-
	EPA	10	18	29	n	9	1.8	-
EPA 2	Ours	74	368	102	1	72	16	-
	EPA	79	402	92	n	67	16	-
EPA 3	Ours	370	720	na	<1	320	70	-
	EPA	367	769	350	n	314	73	-
EPA Hg	Ours	-	-	-	-	-	-	2.4
	EPA	-	-	-	-	-	-	2

n - not added; na - not available

TABLE V1

Metal Contents of Sludges (100^{O}C dried)

	Cd	Cr	Pb	Ni	Cu	Hg	Mn	Ag	Zn	Fe	Al
	ppm									%	
Toronto Plant A	50	4300	1600	350	1300	10	300	na	7700	1.7	na
B	15	550	890	30	1030	24	360	60	2200	7.4	1.3
C	147	4500	4000	900	2200	12	350	na	19000	3.0	na
Newmarket	2	16	85	7	162	1	210	10	610	0.33	0.10
Point Edward	6	67	250	23	540	3	60	4	855	0.60	3.9
Thornhill	6	35	200	30	3000	8	500	na	1200	1.0	na
Aurora	9	16000	220	180	600	5	270	na	900	0.80	na
Kitchner	17	11000	480	525	625	13	500	na	3380	1.1	na
Oshawa	5	1500	3000	1500	450	2	280	na	5000	2.4	na

na - not available

TABLE VII

Metal Contents of Fertilizers (100°C dried)

Brand	Cd	Cr	Pb	Ni	Cu	Hg	Mn	Zn	Fe
	ppm								%
1	63	6000	450	75	450	16	170	1400	5.0
2	43	2900	390	60	250	8	125	900	2.9
3	<1	25	10	4	45	0.4	42	30	0.15
4	<2	15	20	10	50	<1	45	200	0.55

Brands (1) and (2) are made from sludge. Brands (3) and (4) are an inorganic and turkey manure formulation, respectively.

C. Metal Content of Liquids

Liquids coexisting with sludges were filtered through various porosity filters. Liquids thus obtained were analyzed by both "extractable" and "total" metal procedures. Available results are given in Tables VIII and IX.

TABLE VIII

Extractable Metals in Sludge Liquids (ppb)

Location	Filter	Zn	Fe	Pb	Ni	Cu	Cd
North Toronto	60μ	18	40	<1	29	29	<0.2
	0.45μ	<1	30	<1	31	21	<0.2
Newmarket	0.45μ	<1	20	<1	<1	4	<0.2

TABLE IX

"Total Metal" in Sludge Liquids (ppb)

Location	Filter	Zn	Fe	Pb	Ni	Cu	Cd	Hg
North Toronto	60μ	235	57	<2	125	530	1	1.4
	5μ	195	50	<2	115	550	1	1.1
	0.45μ	75	33	<2	110	540	1	1.0
Newmarket	60μ	70	56	<2	65	25	1	-
	5μ	60	50	<2	62	25	1	-
	0.45μ	60	50	<2	65	25	1	-

These data suggest that the majority of the sludge water metal is bound tightly and hence is not readily detectable using the extractable metal procedure. Nickel, Cu and Cd results appear to be little affected by the filter porosity size. Lead, although not detected in any of the liquids above, was found to be present in the solids residue trapped by the 60μ porosity filter.

Detection limits for the liquids were as follows: Cd and Zn, 0.2 ppb, Fe, Pb, Cu and Ni 1 ppb.

The high metal levels outlined for sewage treatment plant products in this and other studies suggest need for research into the fate of these metals upon interacting with terrestrial and aquatic environments.

WORK IN PROGRESS

Anodic Stripping - Polarography

Equipment for these techniques is much less expensive than atomic absorption instrumentation. In this regard it is of interest to find if these techniques can be useful in analysing metals in sludge or wastewater samples.

At this early stage (June 1974) in the case of sludge, it

would seem that even for the easiest to analyze metals (Cu, Cd, Pb, Zn) these techniques are very fraught with very troublesome interference problems. For wastewaters on the other hand, the techniques show some promise when applied to Cu, Pb, Cd and Zn analyses.

Method for Mo, As and Se

At the present time (June 1974) a simple and rapid non-flame atomic absorption method for these elements is being developed.

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EXTRACTABLE METALS IN MIXTURES OF SOIL AND SEWAGE SLUDGE*

by

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ABSTRACT

Five anaerobically digested sewage sludges including lime treated sludge from Newmarket, untreated sludge from Ottawa, alum treated sludge from Point Edward and iron chloride treated sludges from North Toronto and Sarnia were mixed and incubated with six soils. The soils were acid and exhibited wide ranges of clay and organic matter contents. Sulphur, phosphorus and lime ($CaCO_3$) were added to some of the mixtures. Extractable metals were measured in 0.05M EDTA, 0.005M DTPA and 0.01M $CaCl_2$ before and/or after incubation.

The Ottawa, Point Edward, North Toronto and Sarnia sludges caused increases in the levels of extractable soil metals which appeared to be related to sludge rate and metal content and independent of chemical treatment. Generally, Newmarket caused small increases but occasionally decreases, probably because it contained small amounts of metals and caused large increases in soil pH. Adding lime increased soil pH and reduced metal extractabilities but the reduction were far outweighed by the increases due to adding sludge. The effects on metals of adding sulphur and phosphorus were negligible compared to adding sludge.

Zinc extractability varied with soil texture and was greater from sandy than clay soils, however, there was little if any relationship between extractability and texture for any of the other metals. Extractable Zn, Ni, and Co were greater for soils with high soluble organic matter contents; Pb, Cu and Cd exhibited no consistent relationship with soil organic matter. Cadmium appeared to remain highly soluble in soils because the very small amounts in the sludges increased the extractable levels and 0.01M $CaCl_2$ extracted measurable amounts.

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INTRODUCTION

There is overwhelming evidence, mainly from England, that trace metal pollution of agricultural land can result from the use of sewage sludge (Bates, 1972 and Page). It is reported that "instances of crop damage caused by build-up of toxic levels of one or more metals in the soil, usually after dressings of sewage sludge, repeated over a number of years are known to every agricultural advisor. .... The two conditions which lead to damage are the continued and repeated application of heavy dressings over a longtime and the use of sludges from industrial areas containing large quantities of toxic metals" (Patterson 1971). Ontario sludges exhibit a wide range of metal contents (Abbott, 1971) and in some areas have been spread on agricultural land for many years (Bell, 1971). Since many metals remain in the soil almost indefinitely it is essential that maximum permissible levels be established and that they be incorporated into guidelines for sludge use.

Toward this end, studies are in progress at the Soil Research Institute, Ottawa to determine the solubilities of sludge metals in soils having a range of pH and clay and organic matter contents and subjected to a variety of simulated environmental conditions such as wetting, drying, freezing, thawing, aerobiosis and anaerobiosis. The following reports the results of studies in which (1) four rates of four sludges were added to one soil (2) one rate of four sludges was added to six soils and (3) one rate of one sludge was added to four soils untreated and treated with sulfur, phosphorus and lime.

MATERIALS AND METHODS

Soils

A brief description and selected properties of the soils are presented in Table 1. The soils were acid and exhibited wide ranges of texture and organic matter contents. St. Thomas, Vaudreuil and Grimsby were light textured with a range of organic matter contents and Haldimand, Rideau and Wendover were heavy textured with a range of organic matter contents.

Table 1. Description and selected properties of the soils

Series	Great Group	Sample depth (cm)	pH	Organic matter %	Sand %	Silt %	Clay %	Texture
St. Thomas	Humo-Ferric Podzol	0-30	5.2	1.8	91.9	6.8	1.3	sand
Vaudreuil	Humic Gleysol	2-5	5.1	5.8	72.7	23.7	3.6	sandy loam
Grimsby	Grey Brown Luvisol	0-15	4.3	0.6	43.7	48.9	7.4	silt loam
Haldimand	Grey Brown Luvisol	0-15	4.8	2.3	11.3	52.3	36.4	silty clay loam
Rideau	Gleyed Eutric Brunisol	8-17	5.3	1.0	5.7	49.1	45.2	silty clay
Wendover	Melanic Brunisol	0-3	5.4	9.4	6.7	47.9	45.4	silty clay

Sludges

Anaerobically digested, lime treated sludge from Newmarket, untreated sludge from Ottawa, alum treated sludge from Point Edward and iron chloride treated sludges from North Toronto and Sarnia were used for the studies. The metal contents of the sludges (Table 2) were determined by atomic absorption after digestion in aqua regia (Van Loon and Lichwa, 1973). The Newmarket, North Toronto and Ottawa sludges were taken on two sampling dates and analyses are given for samples I and II. Newmarket II and North Toronto II were vacuum filter cake materials and Ottawa II was obtained after drying several months in a lagoon. All of the other sludges were suspensions obtained directly from anaerobic digestors. Newmarket contained small amounts, Ottawa and Point Edward approximately equal, intermediate amounts, and North Toronto and Sarnia large amounts of metals. Sarnia contained very large amounts of Zn and Pb and a relatively large amount of Cd. North Toronto contained large amounts of Zn, Pb and Cr. All but Newmarket contained appreciable amounts of Cu and all contained small amounts of Co.

Soil-Sludge Mixtures

The soils and sludges were used to prepared mixtures as follows:

A. Haldimand soil with 0.6, 1.25, 2.5 and 5 % of Newmarket I, Ottawa I, Point Edward and North Toronto I sludges.

B. St. Thomas, Vaudreuil, Grimsby, Haldimand, Rideau and Wendover soils with 2.5% of Newmarket II, Ottawa II, North Toronto II Sarnia sludges.

C. St. Thomas, Vaudreuil, Haldimand and Wendover soils with 10% of Point Edward sludge.

The 0.6, 1.25, 2.5, 5 and 10% rates denote 0.6, 1.25, 2.5, 5 and 10 g respectively, of sludge solids per 100 g of soil. The 0.6 and 1.25% treatments of A mixtures were prepared with sludge suspensions containing approximately 5% solids, and the 2.5 and 5% treatments with freeze-dried sludges, as were the 10% treatments of C mixtures. The moisture contents

Table 2. Metal contents of the sludges

Metal	Sludges[1]							
	Newmarket		Ottawa		Point Edward	North Toronto		Sarnia
	I	II	I	II		I	II	
	ppm (70 C dry solids basis)							
Zn	891	488	1155	na[2]	1198	2422	2740	10045
Pb	149	122	663	na	390	1042	1807	3530
Cu	179	182	636	na	676	988	1317	878
Ni	39	14	107	na	34	36	28	31
Cd	4.0	5.3	11.6	na	8.3	16.5	37	99
Co	20	na	14	na	11	21	na	na
Cr	33	31	121	na	161	1210	838	166

I, II denote different sampling dates.

1 Newmarket sludge was treated with lime; Ottawa, untreated; Point Edward, alum treated; and North Toronto and Sarnia, iron chloride treated.

2 data not available.

of air-dry sludges were determined by heating in an oven at 70°C and appropriate amounts of the air-dry materials were mixed with soils to prepare the B mixtures. One hundred ppm S (soil basis) as elemental sulphur, 250 ppm P (soil basis as $Ca(H_2PO_4)_2 \cdot 2H_2O$ and lime ($CaCO_3$) were added to the appropriate treatments of C mixtures. The $CaCO_3$ was added as required to increase the soil pH to 7.5, except that an error was made and the rate for Wendover soil was added to Vaudreuil and vice-versa. Consequently, the pH of limed Wendover soil was only about 6.5. Air-dry soil was used to prepare all of the mixtures.

Following preparation, the mixtures were wetted approximately to field capacity with distilled water and A and C were incubated at room temperature and B at 25 ±1°C in closed plastic containers. During incubation, they were mixed and aerated at two-day intervals to maintain aerobiosis and when necessary water was added to maintain the appropriate moisture content.

Soil-Sludge Analysis

Samples of the A, B and C mixtures for analysis were air-dried and ground to pass a 2 mm sieve. The A mixtures were extracted by shaking 1:2 soil and 0.05M EDTA in 0.01M $CaCl_2$ buffered at pH 7.3 with 0.1M triethanolamine, for ½ hr. The B and C mixtures were extracted by shaking 1:2 soil and 0.005M DTPA in 0.01M $CaCl_2$ buffered at pH 7.3 with 0.1M triethanolamine, for 2 hr. In addition, the B mixtures were extracted by shaking 1:2 soil and 0.01M $CaCl_2$ for 2 hr. The suspensions were centrifuged momentarily at 1250 g and the extracts filtered through Whatman No. 42 filter papers. Metals in the extracts were determined by atomic absorption spectrophotometry. Preliminary studies indicated that the extracts could be stored in a refrigerator for several days prior to making the measurements. Refrigeration prevented precipitation and fungal growth which occurred when they were stored at room temperature. Soil pH was determined in 1:2 suspensions of soil and 0.01M $CaCl_2$.

RESULTS

Four Rates of Four Sludges Added to One Soil

Adding lime treated Newmarket, untreated Ottawa, alum treated Point Edward and iron chloride treated North Toronto sludges and incubating at room temperature increased the levels of 0.05M EDTA-extractable metals in Haldimand silty clay loam soil (Table 3). Moist aerobic incubation at room temperature caused changes in some but not all of the metal levels. In the no sludge soil, Pb decreased from 5.5 to 1.7 ppm but the other metals remained unchanged. In the sludge treated soils, the levels of Zn and Pb decreased and this was most marked for the 2.5 and 5.0% rates. Ni showed a small but general increase and Cu and Cd remained unchanged. All of the sludges increased the soil pH, however the changes were larger with the lime treated Newmarket than the others. The 0.6% rate of Newmarket produced about the same increase as the 5.0% rates of the others. All of the sludges increased the levels of extractable Zn, Cu, Ni, Pb and Cd in the soil and the increases appeared to be related to the metal contents (Table 2) and the rates of addition (Table 3). North Toronto sludge exhibited the highest metals content and produced the largest increases, Point Edward and Ottawa had similar intermediate metals contents and caused approximately equal, smaller increases and Newmarket contained the least metals and caused the smallest increases. The Ni and Cd contents of all the sludges were small and any increases were correspondingly small, however, Ottawa had the highest Ni content and Ottawa and North Toronto the highest Cd contents and they produced the highest extractable levels of these metals, respectively. Extractable Zn and Cu increased with increasing rates of sludge addition. Pb showed some increases immediately after adding sludge but after incubation, generally showed decreases with increasing sludge rates. This effect was most marked for the lime treated Newmarket sludge. The levels of extractable Cr, even in soil treated with North Toronto sludge which contained 1210 ppm Cr, were too low to measure.

One Rate of Four Sludges Added to Six Soils

Adding untreated Ottawa and iron chloride treated North Toronto

Table 3. 0.05M EDTA-extractable metals from Haldimand silty clay loam soil untreated and treated with sludges and incubated at room temperature

Sludge	Rate %	pH	Metal (ppm, soil basis)									
			Zn		Pb		Cu		Ni		Cd	
			Incubation period									
		1	0	1	0	1	0	1	0	1	0	1
no sludge	0	4.6	2.3	2.3	5.5	1.7	1.8	1.6	1.5	1.6	0.3	0.2
Newmarket I	0.6	6.1	4.1	2.9	7.9	5.2	3.8	3.7	1.4	1.6	0.2	0.2
	1.25	6.8	6.2	3.5	7.1	4.2	4.2	3.8	1.4	1.3	0.2	0.2
	2.5	7.4	7.0	4.7	2.8	2.2	3.8	4.2	1.0	2.7	0.3	0.2
	5.0	7.7	11.9	6.5	4.0	2.5	5.2	4.5	1.2	2.5	0.5	0.2
Ottawa I	0.6	4.9	5.6	6.3	10.2	8.3	5.0	5.6	1.6	2.0	0.2	0.3
	1.25	5.3	7.8	6.7	13.3	10.7	7.0	7.1	2.0	1.9	0.3	0.2
	2.5	5.9	12.5	11.5	13.1	4.4	8.6	12.4	2.2	3.2	0.6	0.4
	5.0	6.4	23.3	8.0	22.1	7.0	14.7	22.1	3.3	4.1	0.7	0.6
Point Edward	0.6	4.8	7.1	5.7	10.8	7.0	5.2	5.1	1.6	1.6	0.8	0.2
	1.25	5.0	9.0	8.5	12.7	8.5	8.6	8.5	1.6	1.7	0.3	0.2
	2.5	5.7	9.6	6.6	6.4	3.8	8.5	10.5	1.4	2.2	0.4	0.3
	5.0	5.8	18.3	9.6	9.8	5.6	18.9	19.1	1.5	2.7	0.4	0.4
North Toronto I	0.6	4.8	7.5	9.1	9.8	3.7	7.1	7.1	1.6	1.7	0.2	0.3
	1.25	4.9	14.4	15.3	14.8	10.3	11.9	11.3	1.5	1.7	0.3	0.3
	2.5	5.9	37.0	19.1	19.9	6.3	13.9	20.9	1.5	2.9	0.6	0.5
	5.0	6.0	61.5	39.4	29.6	9.5	30.8	39.1	1.6	2.9	0.7	0.8

0 extracted immediately after adding sludge

1 extracted the 0.6 and 1.25% treatments after incubation for 25 days and the 2.5 and 5.0% after 71 days

and Sarnia sludges and incubating at 25°C increased the levels of 0.005M DTPA- extractable metals in the soils and the magnitude of the increases appeared to be related to the metal contents of the sludges (Table 4). For example, the Zn contents of the sludge increased in the order Ottawa, North Toronto and Sarnia (Table 1) and the levels of extractable Zn in the treated soils increased in the same order. Sarnia contained very large amounts of Zn, Pb and Cd and caused very high extractable levels relative to the other sludges and to no sludge. North Toronto contained more Cu and caused higher extractable levels than Sarnia. The lime treated Newmarket sludge contained small amounts of metals and it generally decreased the extractable levels in the soils. None of the sludges contained large amounts of either Ni or Co and the extractable levels of these were approximately the same as for the no sludge treatment. The no sludge treatment Vaudreuil, Grimsby and Wendover soils and all of the Sarnia sludge treated soils contained appreciable amounts of 0.01M $CaCl_2$-soluble Zn. Similarly, some of the Sarnia and North Toronto sludge treated soils contained increased levels of 0.01M $CaCl_2$-soluble Cd. The levels of extractable Sn, Cr, Mo and Ag were too low to measure in any of the extracts. All of the sludges increased the pH of the soils and the changes were larger with the lime treated Newmarket sludge than with the others. Newmarket increased the pH to about 7.5 whereas the others produced a range of values from 5.6 to 7.0.

Incubation at 50°C caused changes relative to 25°C for some but not all of the metals. The levels of extractable metals in the no sludge soils incubated at 25°C were low except for Zn and Pb in Vaudreuil and Wendover. Incubating at 50°C, increased soil pH and generally decreased extractable Zn, Cu and Ni. Lead did not change and Co and Cd generally increased. Similar changes were observed for the soils treated with Sarnia sludge, however, the metal levels were much higher than in the no sludge soils. The levels of 0.01M $CaCl_2$-extractable Zn and Cd in the no sludge and Sarnia treated soils were generally lower after incubation at 50°C than at 25°C.

Zinc extractability varied with soil texture and was greater from the sandy than the clay soils. However, there was little if any relation-

Table 4. Extractable metals[1] from soils untreated and treated with 2.5% sludge and incubated at 25 or 50 C for 42 days

Soil	Sludge	pH	Metal (ppm soil basis) .005M DTPA Zn	Pb	Cu	Ni	Co	Cd	0.01M $CaCl_2$ Zn	Cd
St. Thomas	no sludge[2]	5.1	5.5	2.0	1.8	.22	.10	.06	.40	.01
	no sludge	5.7	3.4	2.0	1.1	.41	.23	.10	.10	nd[3]
(Sand, 1.8% O.M.[4])	Newmarket II	7.7	4.9	1.5	2.2	.22	.14	.49	.01	nd
	Ottawa II	6.7	12	7.1	12	.77	.27	.24	.12	nd
	North Toronto II	7.1	22	7.8	12	.28	.20	.49	.06	.01
	Sarnia[2]	6.4	92	18	11	.29	.19	1.19	1.53	.04
	Sarnia	6.5	41	11	5.6	.22	.23	1.31	.57	.01
Vaudreuil	no sludge[2]	4.4	13.3	6.6	1.1	.86	.54	.23	1.54	.05
	no sludge	5.6	4.7	5.7	1.1	.48	.46	.19	.27	nd
(Sandy loam, 5.8% O.M.)	Newmarket II	7.5	7.8	3.3	2.0	.53	.25	.22	nd	.03
	Ottawa II	6.1	20	9.7	12	1.54	.27	.41	.30	nd
	North Toronto II	6.6	25	8.9	11	.68	.25	.73	.08	.04
	Sarnia[2]	5.6	116	14	6.8	.78	.51	1.50	6.03	.08
	Sarnia	6.3	62	22	6.8	.50	.31	1.31	.96	nd
Grimsby	no sludge[2]	4.2	2.0	1.0	1.0	.25	.24	.06	1.44	.05
	no sludge	4.4	1.2	0.8	0.7	.20	.39	.45	.47	.13
(Silt loam, 0.6% O.M.)	Newmarket II	7.6	2.0	1.0	2.1	.19	.23	.07	nd	.03
	Ottawa II	6.1	6.8	4.9	10.6	.29	.11	.26	.17	nd
	North Toronto II	7.1	14	6.8	11	.17	.11	.48	.01	.04
	Sarnia[2]	5.9	54	16	7.5	.24	.25	1.23	2.78	.15
	Sarnia	5.9	28	10	5.6	.12	.16	1.30	1.06	.10
Haldimand	no sludge[2]	4.7	1.8	2.6	1.0	.64	.21	.10	.16	.02
	no sludge	5.5	0.7	2.6	1.2	.41	.58	.55	.02	.01
(Silty clay loam, 2.3% O.M.)	Newmarket II	7.6	1.7	1.8	2.0	.42	.32	.10	.02	nd
	Ottawa II	6.3	6.0	8.2	11	.84	.29	.26	.08	nd
	North Toronto II	6.7	14	8.0	11	.48	.32	.56	.04	.02
	Sarnia[2]	6.2	43	22	6.4	.24	.34	1.10	.42	.02
	Sarnia	6.5	16	18	4.0	.22	.31	1.25	.07	nd
Rideau	no sludge[2]	5.2	1.0	0.3	0.6	.22	.03	.05	.02	.03
	no sludge	5.6	0.5	0.6	0.4	.24	.26	.13	.02	nd
(Silty clay, 1.0% O.M.)	Newmarket II	7.6	2.6	1.0	2.3	.23	.23	.08	.02	.02
	Ottawa II	6.7	6.1	5.8	9.2	.58	.25	.18	.07	nd
	North Toronto II	7.0	14	6.2	8.9	.29	.04	.41	.02	.07
	Sarnia[2]	6.4	39	20	5.3	.28	.18	.95	.16	.05
	Sarnia	6.6	13	15	3.6	.19	.27	1.25	.04	.01
Wendover	no sludge[2]	5.0	8.1	5.2	1.4	1.38	.86	.20	.13	.02
	no sludge	6.0	1.9	1.2	2.1	.54	.73	.36	.07	nd
(Silty clay, 9.4% O.M.)	Newmarket II	7.3	4.1	3.1	1.8	.82	.29	.17	nd	.02
	Ottawa II	5.8	18	11	12	2.31	.32	.40	.22	nd
	North Toronto II	6.1	24	9.0	10	1.38	.25	.72	.10	.04
	Sarnia[2]	5.7	87	14	7.0	1.44	.51	1.55	1.72	.02
	Sarnia	6.4	17	12	5.9	.56	.73	1.48	.12	nd

[1] Sn, Cr, Mo and Ag were not detected in the extracts

[2] Incubated at 50 C

[3] Not detected

[4] Organic matter

ship between extractability and texture for any of the other metals. The levels of extractable Zn, Ni and Co appeared to show a relationship with the organic matter contents of the soils. Vaudreuil and Wendover contained large amounts of organic matter and the levels of these metals were higher in them than in the other soils. Extractable Pb, Cu and Cd did not appear to be related to the organic matter contents of the soils although the levels of Pb and Cd in Vaudreuil and Wendover with no sludge were higher than in the other soils with no sludge.

Sulphur, Phosphorus, Lime and One Sludge Added to Four Soils

Adding Point Edward sludge increased the levels of 0.005M DTPA-extractable metals in all soils (Table 5). The sludge contained large amounts of Zn and Cu and smaller amounts of Pb, Ni and Cd (Table 1) and these differences are reflected in the levels of extractable metals. Small pH changes occurred during incubation at room temperature. Generally, there were slight reductions in the sulphur and phosphorus treated soils and slight increases in the lime and sludge treated soils. Extractable Zn remained constant during incubation in the no sludge soils and generally decreased slightly in the sludged soils. Copper, nickel and cadmium remained almost constant in all the soils and pB remained almost constant in St. Thomas, Haldimand and Rideau, and increased in the Vaudreuil soil.

The sulphur and phosphorus treatments exhibited little effect on the levels of extractable metals in the soils except for an approximately 50% reduction of Zn and Pb in Vaudreuil. Lime reduced the metal levels. Sludge greatly increased extractable Zn, Cu and Pb and somewhat increased Ni and Cd. After incubation the sludge plus phosphorus and sludge plus sulphur treatments exhibited higher levels of extractable Zn and marginally higher Pb, Ni, Cu and Cd than the sludge plus lime or sludge plus lime plus phosphorus treatments. Zinc extractability was high in the sandy soils and in the high organic matter clay soil; it was lower in the low organic matter clay soil. There was more extractable Ni in the high organic matter soils than in the others. Lead, Cu and Cd extractability appeared to be related to neither soil texture nor organic matter content.

Table 5. 0.005M DTPA-extractable metals from soils treated with 10% Point Edwards' sludge, lime, phosphorus and sulfur and incubated at room temperature

Soil	Treatment	pH		Metal (ppm, soil basis)									
				Zn		Pb		Cu		Ni		Cd	
		Incubation period (days)											
		0	100	0	100	0	100	0	100	0	100	0	100
St. Thomas	nil[1]	5.1		5.5		2.0		1.8		.22		.10	
(Sand, 1.8% O.M.[2])	S	5.4	4.9	4.8	5.8	1.4	1.9	0.9	1.1	.38	.34	.15	.08
	P	5.3	5.1	7.2	6.2	1.8	1.9	1.2	1.2	.28	.48	.15	.09
	L	6.8	7.4	3.4	3.0	1.2	1.2	0.9	0.9	.28	.22	.11	.07
	P+L	6.4	6.9	4.0	3.4	1.2	1.2	1.0	0.8	.26	.16	.07	.08
	S+ SL	6.6	6.5	31	33	7.4	5.6	19	20	.54	.68	.39	.33
	P+ SL	6.4	6.5	30	27	7.4	7.0	20	17	.58	.64	.43	.26
	L+SL	6.9	7.2	28	23	6.8	7.3	19	17	.44	.64	.41	.20
	P+L+SL	6.8	7.0	30	23	6.8	6.9	21	16	.48	.48	.39	.30
Vaudreuil	nil[1]	4.4		13		5.7		1.1		.86		.19	
(Sandy loam, 5.8% O.M.)	S	5.2	4.3	6.4	6.8	2.0	1.1	1.2	0.3	.96	.70	.20	.14
	P	5.1	4.3	6.8	10	3.1	3.3	1.4	0.6	.96	.70	.20	.18
	L	7.2	7.3	5.6	2.0	3.3	2.0	1.3	0.5	1.04	.56	.22	.12
	P+L	6.8	6.9	6.2	3.0	3.4	2.4	1.3	0.4	1.00	.42	.20	.14
	S+ SL	6.2	6.2	33	27	4.0	9.8	17	18	1.24	1.08	.52	.50
	P+ SL	6.2	6.1	30	33	3.1	9.5	17	18	1.08	2.06	.50	.50
	L+SL	7.2	7.2	29	18	6.6	7.9	19	16	1.20	.92	.50	.28
	P+L+SL	6.8	7.0	31	21	7.0	8.3	19	16	1.34	.76	.42	.40
Haldimand	nil	4.8	4.7	2.0	2.0	3.0	2.0	1.0	0.9	.62	1.10	.12	.14
(Silty clay loam, 2.3% O.M.)	S	4.8	4.5	2.0	2.1	2.6	2.3	1.0	1.1	.58	.88	.12	.12
	P	4.8	4.7	2.8	2.2	2.8	2.3	1.1	0.9	.62	.80	.15	.12
	L	7.1	7.5	0.8	0.7	1.8	1.2	0.8	0.7	.48	.66	.12	.08
	P+L	7.0	7.3	0.8	1.1	1.4	1.2	0.7	0.7	.44	.62	.11	.08
	S+ SL	6.3	6.2	23	11	9.0	8.2	20	20	.72	.60	.50	.44
	P+ SL	6.1	6.3	25	12	8.8	7.7	20	20	.74	.72	.26	.42
	L+SL	7.1	7.3	20	6.8	8.4	6.1	19	17	.64	.46	.42	.30
	P+L+SL	7.0	7.2	23	6.8	8.8	6.2	22	18	.80	.48	.48	.34
Wendover	nil[1]	5.0		8.1		5.2		1.4		1.38		.20	
(Silty clay, 9.4% O.M.)	S	5.4	5.0	8.8	4.6	3.0	0.8	0.6	1.0	.56	.98	.16	.22
	P	5.2	5.1	9.2	5.0	4.9	0.9	0.6	0.8	.74	1.16	.14	.22
	L	6.1	6.4	3.4	2.2	2.9	2.9	0.5	1.0	.42	.90	.12	.16
	P+L	5.8	6.3	4.8	2.8	3.3	3.0	0.7	1.0	.52	.86	.12	.18
	S+ SL	6.1	5.9	35	25	9.0	5.7	19	18	.96	1.44	.52	.60
	P+ SL	6.3	6.0	36	28	8.3	5.3	20	18	1.10	1.58	.50	.64
	L+SL	6.1	6.5	26	20	8.1	8.5	16	18	.82	1.18	.38	.50
	P+L+SL	6.4	6.5	30	22	8.1	8.5	18	18	.82	1.38	.44	.50

L: $CaCO_3$ was added to increase the soil pH to 7.5 except that an error was made and the rate for Wendover soil was added to Vaudreuil and vice versa

SL: Sludge

P: 250 ppm P (soil basis) added as $Ca(H_2PO_4)_2.2H_2O$

S: 100 ppm S (soil basis) added as elemental sulfur

[1] Data for nils taken from the 25 C no sludge treatments of Table 4

[2] Organic matter

DISCUSSION

The foregoing results represent a portion of the Soil Research Institute effort to determine the fate of sludge metals in soils. The studies on adding (1) four rates of four sludges to one soil, and (2) sulphur, phosphorus, lime and one sludge to four soils are completed. The study on adding (3) four sludges to six soils and incubating at 25 and 50°C is in progress and further measurements will be done after incubation for 84 days. In addition, studies are in progress to determine effects on metal extractabilities in soil-sludge mixtures of (4) adding increments of sludge at 42 day internals during incubation at 25 and 50°C (5) alternate freezing and thawing, (6) continuous freezing, (7) alternate anaerobiosis and aerobiosis, and (8) continuous anaerobiosis. Also, (9) studies will be undertaken with Midland and Guelph sludges which contain large amounts of Ni and Cd, respectively.

To date, the metals have been extracted from soils mainly with 0.005M DTPA although some extractions were done with 0.05M DTPA, 0.05M EDTA, 0.01M $CaCl_2$ and 0.5N HOAc. Preliminary studies indicated that the 0.05M EDTA, 0.05M DTPA and 0.005M DTPA-extractable metals were highly correlated. The 0.05M EDTA and DTPA generally extracted somewhat more metals but the differences were not considered large enough to warrant changing from the standard 0.005M DTPA method (Lindsay and Norvell, 1969) which has been used fairly widely in the United States and Canada to provide an index of metal availability for plants growing in soils (Brown et al, 1971; McGregor, 1972, and; Haq and Miller, 1972). Extractions are in progress with 0.5N HOAc to provide a comparison of measurements with published information from England (Webber,1972 and Page, n.d.). The 0.01M $CaCl_2$ is a neutral salt and approximates the concentration of soil solutions. Thus, extracting soils with 0.01M $CaCl_2$ is thought to provide an estimate of metal concentration in the soil solution. The fact that Cd levels in 0.01M $CaCl_2$ were large enough to measure, given the small amounts in the sludges (Table 1), indicates that Cd remains highly soluble in soils.

The six soils (Table 1) were moderately to strongly acid and exhibited a wide range of texture and organic matter contents. A range of soil pH was obtained by adding lime ($CaCO_3$). It is generally believed that metal solubilities are related to pH, and the amounts of clay and

organic matter in soils. The five sludges (Table 2) were anaerobically digested and included lime treated sludge from Newmarket, untreated sludge from Ottawa, alum treated sludge from Point Edward, and iron chloride treated sludges from North Toronto and Sarnia. They are the various kinds of sludges being produced in Ontario which will be spread on land and they exhibited a wide range of metal contents.

The most noticeable effect of adding sludges to soils was that they increased the levels of extractable metals. The increases appeared to be related to sludge rate and metal content, independent of whether the sludge was untreated or treated with iron chloride or alum (Tables 3, 4 and 6). The lime treated sludge generally caused small increases and occasionally reductions, probably because it contained small amounts of metals and caused large increases in soil pH.

Adding lime increased soil pH and reduced metal extractabilities but the reductions were far outweighed by the increases due to adding sludge (Table 5). After incubation the metal levels were only marginally lower in the limed than in the unlimed treatments. The effects on metals of adding 250 ppm phosphorus or 100 ppm sulfur were negligible compared to adding sludge. These rates are equivalent to 500 lb/acre phosphorus and 200 lb/acre sulphur and are large compared to the rates normally employed in agricultural practice.

Zinc extractability varied with soil texture and was greater from the sandy than the clay soils, however, there was little if any relationship between extractability and texture for any of the other metals. Extractable Zn, Ni and Co were greater for soils with high organic matter contents. Lead, Cu and Cd exhibited no consistent relationship with soil organic matter. There were insufficient date to warrant comment concerning the effects of incubation temperature and time on the levels of extractable metals.

Data for the six soils were widely variable, however, it was estimated that 0.005M DTPA extracted approximately 15% of the Zn and Pb, 30% of the Cu, 10% of the Ni and 40% of the Cd added in the North Toronto, Sarnia and Point Edward sludges. The values were generally lower for Newmarket and were not available for Ottawa sludge. The 0.05M EDTA extracted approximately 20% of the Zn and Pb, 60% of the Cu, 80% of the Ni and 65%

Table 6. Percentages of metals extracted with 0.005M DTPA and 0.05M EDTA after incubating mixtures of sludge and Haldimand soil

Metal	Sludges				
	Ottawa	Newmarket	North Toronto	Sarnia	Point Edward
			DTPA		
Zn	na[1]	0	20	16	7.5
Pb	na	17.4	12	23	26
Cu	na	0	30	24	0
Ni	na	0	0	8	26
Cd	na	0	50	40	31
			EDTA		
Zn	32	11	28	na[1]	14
Pb	16	16	18	na	21
Cu	67	58	77	na	52
Ni	60	100	100	na	67
Cd	67	0	75	na	50

[1] not available

of the Cd in Ottawa, Newmarket, North Toronto and Point Edward sludges added to Haldimand soil. The data for Ni and Cd were erratic possibly because only very small amounts were added. The percentages of metals extracted with 0.005M DTPA and 0.05M EDTA after incubating mixtures of sludge and Haldimand soil are presented in Table 6.

Point Edward sludge contained 2872 ppm "Zn equivalent" calculated according to Zn + 2Cu + 8Ni and mixing 10% of this sludge with soils (Table 5) added 287.2 mg/kg Zn equivalent, which is only slightly more than the 250 mg/kg recommended as an upper limit (A.D.A.S., Advisory Paper No. 10). Similarly, mixing 2.5% Sarnia sludge with soil added 301.2 mg/kg Zn equivalent. Both of these sludge treatment caused large increases in extractable metals, particularly Zn and Cu, and it is important that plant growth and composition be studied on similarly treated soils. Considering the apparent high solubility of Cd in soils it is essential that its effects be considered too.

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CHEMICAL TESTS FOR PLANT AVAILABLE METALS IN SOILS

by

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Chemical soil tests have been used for many years to assess the availability of certain nutrients such as phosphorus, potassium and magnesium in soils. The total amounts of a nutrient in different soils are not usually closely related to the amounts available to plants. A chemical extractant must therefore be found that removes a fraction of the nutrient from soils which correlates with the amount removed by a crop. Field experiements are then required to determine the growth response of any one specific crop from added nutrient at a given level of extractable nutrient.

In the case of toxic metals the same approach can be used. An extractant must first be found that will remove a portion of the metal which is related to the plant uptake. After this is done further work will be required to determine the level of extractable metal which corresponds to an acceptable concentration in each particular crop or group of crops.

A number of different workers have tested extractants for copper, zinc, with E.D.T.A. and D.T.P.A. often working quite well (Cox and Kamprath, 1972). Haq and Miller (1972) have found that either E.D.T.A. or D.T.P.A. is a suitable extractant for copper; Haq and Miller found them unsuitable on the Ontario soils they tested.

Little work appears to have been done to select extractants for plant availability of metals which are not plant nutrients, such as Cd, Cr, Hg, Ni and Pb. John et al. (1972), found that when he added cadmium to 30 British Columbia soils, ammonium acetate extractable cadmium was significantly correlated with plant cadmium.

The objective of the study which is now in progress is to find the most suitable extractant to measure plant available metals in Ontario soils with particular emphasis on copper and cadmium. Copper and cadmium were chosen because it is expected that, with the exception of zinc for

which an extractant is available, they are important problems in the greatest proportion of sewage sludges.

A group of 35 soils were collected from sites in Ontario believed to have various degrees of contamination with copper and cadmium. A crop of Swiss Chard has been grown on these soils and will be analyzed for metal content. Samples of the soils will then be extracted with a selection of different chemicals (including E.D.T.A., D.T.P.A., and ammonium acetate, among others) and metal uptake by the Swiss Chard will be correlated with metal extracted by the different chemicals. Although the soils were chosen to provide a range of copper and cadmium levels the extractants will be tested for Zn, Cr, Hg, Ni, and Pb as well as Cu and Cd.

From this we hope that we can find an extractant which will provide a dependable measure of plant available metals in Ontario soils.

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DESIGN INFORMATION ON DEWATERING PROPERTIES OF WASTEWATER SLUDGES

by

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Among its diverse responsibilities, the U.S. Environmental Protection Agency administers a construction grant program to upgrade existing and construct new municipal wastewater treatment plants. The research and development effort that supports this program is carried out by the Advanced Waste Treatment Research Laboratory (AWTRL) of the National Environment Research Center (NERC), Cincinnati, Ohio. Research and development activities concerned with the treatment and disposal of municipal wastewater sludges and residues are the responsibility of the Ultimate Disposal Section of AWTRL.

Over the past several years, new technology for phosphate removal has been successfully demonstrated on plant scale under the Environmental Protection Agency's research, development, and demonstration grant program. The demonstrations have necessarily emphasized the performance of the various phosphate removal processes on the treated wastewater and the establishment of design parameters that will ensure satisfactory performance. Plants using the new phosphate removal processes are now being constructed and upgraded, so the need for more precise information and better means of sludge handling has become urgent.

Starting about two years ago, the Ultimate Disposal Section formally included in its program efforts to make more information available on the handling of sludges produced by phosphate removal processes. These efforts have included summaries of useful design information from EPS-funded grants for plant scale study of P-removal processes, visits by field crews to plant sites to collect information on P-removal sludges, and in-house and contract research and development investigations to

fill gaps in information. An interim report on these activities has been prepared and is available from the National Technical Information Service (1). A substantial portion of the information in this paper has been drawn from that report.

ESTIMATES OF DEWATERING RATES

One of the necessary steps in arriving at a minimum cost facility to meet a given wastewater treatment requirement is to "cost out" a number of potential process options in order to identify the more economical approaches. Since dewatering represents a large part of total plant cost in most process alternatives, it is desirable to be able to estimate dewatering rates for defferent types of sludges. Estimates of the relative filtering rates (yields) for various conventional sludges produced from the same wastewater are presented in Table 1. If the yield is known for one type of sludge, the yield for any other sludge can be estimated by using the factors in Table 1. If no estimate of yield is available for one of the sludges, a digested mixture of primary and waste-activated sludge may be assumed to filter at 4.0 lb/hr-ft^2 (19.6 kg/hr-m^2) at a cost of $10/ton ($11/m. ton) of dry solids. The estimates in Table 1 are based on the author's judgement and experience and on a review of available information in the literature. It is presumed that the sludge have been prepared for dewatering by thickening if needed. For example, at some plants sludge is low in solids because it has been withdrawn quickly from the primary clarifier to prevent septicity -- this sludge must be thickened to achieve the dewatering rate indicated in Table 1.

Estimated filtering rates of phosphate removal sludges produced by addition of aluminum (Al) or ferric (Fe) salts, compared with digested primary and WAS sludge (with no Al or Fe) are presented in Table 2. Estimates are based on very limited published information, field visits, and incomplete experimental work. Since Al and Fe sludges usually settle poorly, these rates will probably be achieved only if the sludges are thickened before filtration.

The approximate nature of these estimates must be realized. These estimates will be improved as more information becomes available.

TABLE 1

DESIGN FACTORS FOR FILTRATION OF CONVENTIONAL SLUDGES

Sludge Type	Relative Yield*	Relative Cost of Conditioning**	Cake Solids Content (%)
Raw Primary + WAS***	1.4	0.7	28
Digested Primary + WAS	1.0	1.0	26
Raw Primary + TF****	1.8	0.6	32
Digested Primary + TF	1.3	0.9	30
Digested Primary	2.3	0.7	33
Raw Primary	3.2	0.5	35

* Average yield for digested primary + WAS is estimated at 4.0 lb/hr-ft^2 (19.6 kg/hr-m^3).

** Average cost of conditioning for digested primary + WAS is estimated at $10/dry ton ($11/dry metric ton).

*** Waste activated sludge.

**** Trickling filter sludge.

TABLE 2

DESIGN FACTORS FOR FILTRATION OF SLUDGES PRODUCED WHEN Al^{+++} OR Fe^{+++} ARE USED IN THE WASTEWATER PROCESS

Sludge Type	Relative Yield*	Relative Cost of Conditioning*
Al to Primary		
Raw Primary + WAS**	1.2	1.3
Digested Primary + WAS	0.85	1.4
Raw Primary + TF***	1.35	1.2
Digested Primary + TF	1.0	1.3
Digested Primary	1.05	1.0
Raw Primary	1.5	0.9
Al to Aerator		
Raw Primary + WAS	1.2	1.3
Digested Primary + WAS	0.85	1.4
Fe to Primary		
Raw Primary + WAS	1.3	1.1
Digested Primary + WAS	0.95	1.2
Raw Primary + TF	1.5	1.0
Digested Primary + TF	1.1	1.1
Digested Primary	1.2	0.8
Raw Primary	1.6	0.7
Fe to Aerator		
Raw Primary + WAS	1.3	1.1
Digested Primary + WAS	0.95	1.2

* Yields and costs are related to yield and cost obtained with digested primary + WAS when no chemicals are added to the wastewater. See Table 1

** Waste activated sludge.

*** Trickling filter sludge.

QUANTITIES OF PHOSPHATE REMOVAL SLUDGES

Fe and Al Sludges The mass of chemical sludge produced when Fe or Al salts are added to wastewater is generally estimated from the simplified stoichiometric relationships:

$$M^{+++} + PO_4^{---} \longrightarrow MPO_4 \qquad (1)$$

$$M^{+++} + 3OH^- \longrightarrow M(OH)_3 \qquad (2)$$

Experimental data from a number of sources (1) indicate that the estimate of sludge mass may be low and that it should be increased by up to 35 percent to arrive at a conservative estimate. More data are needed to determine whether this safety factor is excessively large.

If either chemical is added to the primary clarifier, the flocculant precipitate that forms captures suspended solids and absorbs colloidal solids. Kreissl and Westrick's summary paper (2) indicates that suspended solids removals of 85 percent can be achieved by chemical addition for a well operated clarifier. Since conventional clarifiers often operate at suspended solids removal of less than 60 percent, the increase in sludge quantity is substantial.

Kreissl and Westrick's (2) and this author's (1) data indicate that approximately 30 percent of the soluble TOC is removed by addition of an Al or Fe salt in primary clarification. Methods are available for relating mass to TOC (1) and estimating the mass removed from the TOC removed. The mass removed is small, however, and can be accounted for by using an overall safety factor slightly higher than the 35 percent suggested earlier.

If the primary clarifier is followed by a biological process, chemical addition to the primary clarifier greatly reduces the BOD loading, and the mass of waste biological sludge is correspondingly lowered. The reduced quantity of sludge produced by the biological process can be calculated by conventional procedures.

When the chemicals are added to the secondary process or to a tertiary process, the only additional sludge produced is the chemical sludge. It is interesting to compare sludge production of a secondary treatment plant (primary clarifier and the activated sludge process) when the chemicals are added to the primary clarifier in one case and to the activated sludge aerator in the other case.

Sludge production is greater in the first case, because the organic material removed in the primary clarifier is not exposed to biological oxidation, which would have converted some of the material to carbon dioxide and water. It cannot be stated that one method is more cost effective than the other without detailed analysis. The mass of sludge in the first case is greater, but the average dewatering rate of the total mass of sludge could also be greater. In addition, because the BOD loading to the secondary process is reduced, the aeration tank and quantity of air required would be lower.

Lime Sludge Enough information is available to make a reasonable estimate of the additional sludge produced by tertiary treatment with lime (1). The same procedure can be used to estimate sludge production when lime is added to the primary clarifier, provided the additional sludge that results from improved clarifier efficiency is considered. Lime addition does not reduce soluble TOC to any extent, so additional sludge from this source is negligible.

The mass of sludge produced by lime addition depends on the dose of lime required; on the alkalinity of the wastewater; and, to a small degree only, on the phosphate content of the wastewater.

The first step in estimating sludge production is to estimate the pH needed to achieve the desired phosphate removal. Unfortunately, there is no simple way to make this estimate. Small scale laboratory testing is desirable, but a rough estimate can be made from a knowledge of the type of water. For example, to achieve a 90 percent phosphate removal might require a pH of 11 in a soft, low magnesium water, whereas a pH of 10 might be adequate in a hard water with a moderate magnesium content.

The next step is to estimate the dose of lime needed to reach the required pH. Lime is consumed primarily by its reaction with the alkalinity of the wastewater. Consequently, a relationship between lime and alkalinity is anticipated. A good correlation is achieved when the ratio of lime dose to alkalinity is plotted against pH (see Figure 1). If wastewater alkalinity and the desired pH level is known, lime dose can be determined from this correlation.

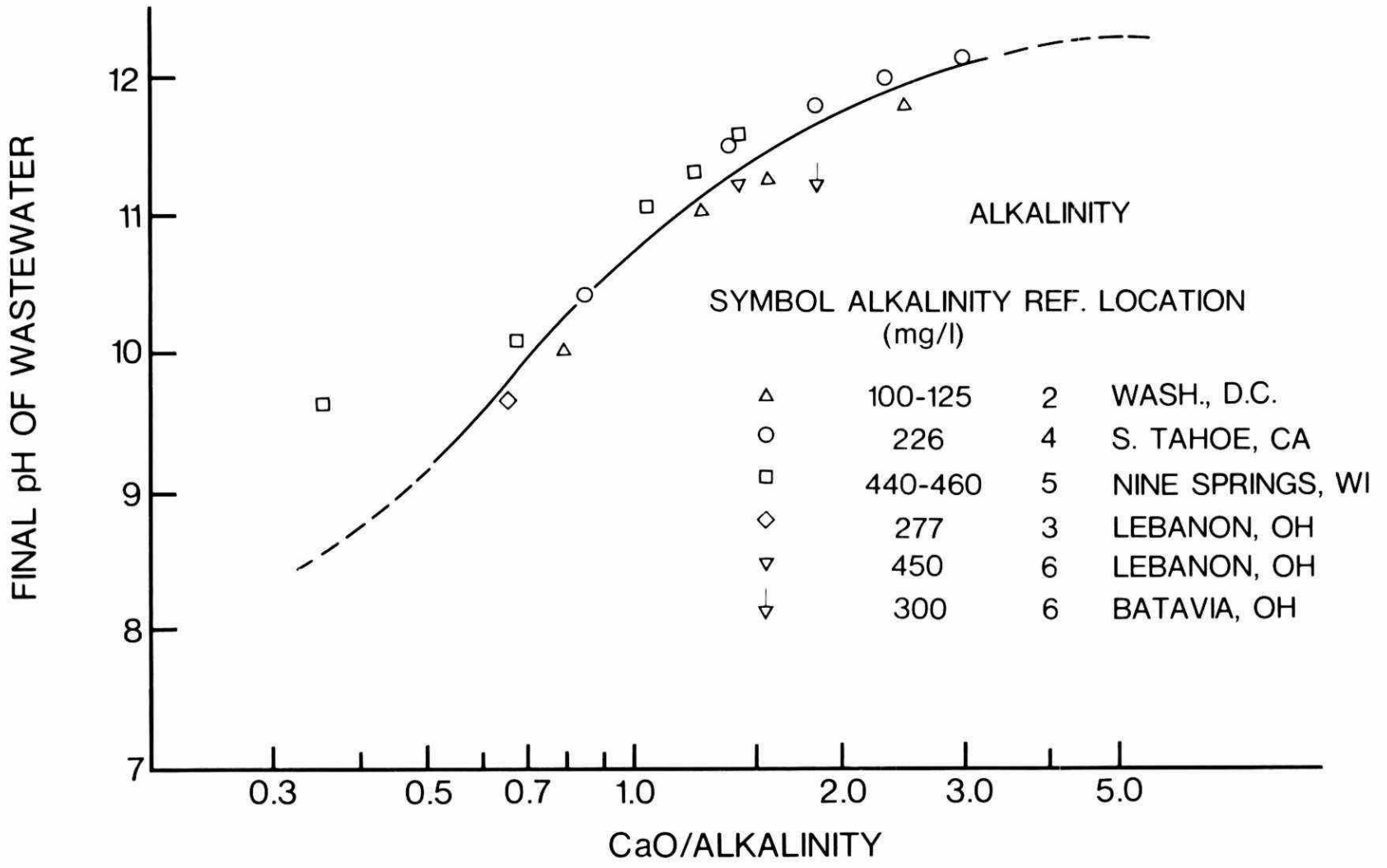

Figure 1. Ratio of Limedose (mg/l) to Initial Wastewater Alkalinity (mg/l)

The primary reactions of lime (CaO) with wastewater are as follows:

$$6HPO_4^{--} + 10Ca^{++} + 20\ OH^- \longrightarrow \underline{2Ca_5(OH)(PO_4)_3} + 6H_2O + 12OH^- \quad (1)$$

$$HCO_3^- + Ca^{++} + 2OH^{--} \longrightarrow \underline{CaCO_3} + H_2O + OH^- \quad (2)$$

$$Mg^{++} + Ca^{++} + 2OH^{--} \longrightarrow \underline{Mg(OH)_2} + Ca^{++} \quad (3)$$

Estimates of residual Ca and Mg after lime addition must be made. Hydroxyapatite sludge produced by phosphate removal is calculated by use of Equation 1, and $Mg(OH)_2$ sludge produced by use of Equation 3. Calcium disappearance is calculated by a Ca balance, and the mass of $CaCO_3$ sludge, equivalent to the Ca disappearance, is calculated by use of Equation 2. Total sludge production is the sum of these three sludge quantities along with the inert solids present in the lime.

Limited data available indicate that calculated lime sludge doses are lower than measured. A safety factor of 20 percent is suggested (1).

DEWATERING RATES

Lime There is probably enough information on sludges produced by lime addition in primary or tertiary processes for most design purposes. There is information on tertiary processes from South Lake Tahoe (3), the Washington, D.C. pilot plant (4), and Butler, Indiana (1). Data on sludges produced by adding lime to the primary are available from Contra Costa (5), Cleveland (1), and Canada (6, 7, 8, 9). Lime sludges generally dewater better than equivalent conventional sludges. There is little chance of grossly undersizing equipment.

Fe and Al Sludges Information is sparse on Fe and Al sludges. Probably the best available information is from Canada (6, 7). Preliminary studies reported by the Eimco Division of Envirotech at Salt Lake City (10) are continuing and should eventually produce definitive data. Eimco staff are utilizing pilot scale equipment to obtain data on thickening, centrifuging, and filtering of sludge produced by Fe and Al addition to primary clarification.

Hathaway and Farrell (11) have shown that Al-primary and Fe-primary sludges gravity-thicken poorly. The rate of thickening is improved by addition of polymer and by dilution with effluent. When both procedures are used together, thickening rates are higher than ordinarily encountered with conventional sludges (over 100 lb/ft^2-day; 500 kg/m^2-day). Final solids concentration of the sludge with either chemical, however, did not exceed 5 percent. Air flotation of these sludges produced solids content as high as 8.4 percent. Statistically designed factorial experiments showed that solids content of floated sludge decreased with increased metals loading in the sludges and increased with increased polymer dosage.

Although a side-by-side comparison was not made, it appeared that Al-primary sludge thickened at least as well as Fe-primary sludges by either gravity or flotation thickening.

Unpublished results by Hathaway have shown that both Al-primary and Fe-primary sludges can be filtered on a Komline-Sanderson coil filter*. Filtration rates (yields) are low (ca. 2 lb/ft^2-hr; 10 kg/m^2-day) even with polyelectrolyte addition. Al-primary sludges filtered at least as well as Fe-primary sludges.

Field Visits with Sludge Trailer Field visits have been made to a number of plant sites with a rented sludge dewatering trailer. This trailer is equipped with various types of thickening and dewatering devices. By using a mobile sludge dewatering facility it is possible to (a) compare effectiveness of a number of dewatering devices for dewatering a given sludge, (b) compare the performance of the dewatering equipment at the plant with the equipment in the trailer, and (c) observe at a number of sites how the performance of each device is affected by differences in sludge type and wastewater source.

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* Mention of proprietary equipment or chemicals does not indicate EPA endorsement.

Cities visited and types of sludges evaluated are shown below:

Plants	Description	Sludges Tested
Beaver Creek, Green County, Ohio	2 MGD, primary + A.S., P-removal by adding Na aluminate to A.S.	a) W.A.S. alone, b) Primary + W.A.S. after aerobic digestion
Defiance, Ohio	4 MGD, primary + A.S., P-removal by adding $FeCl_3$ to A.S.	a) Heat treated primary + W.A.S.
Maumee River, Lucas County, Ohio	25 MGD design (5 MGD actual), no primary, A.S. with contact stabilization, P-removal by adding Na aluminate to incoming wastewater	a) Waste sludge aerobically digested, b) Waste sludge heat treated

In August 1973, the trailer will be brought to Midland, Michigan, which is utilizing ferric chloride for P-removal, and which heat-treats sludge to condition it for vacuum filtration.

Most of our effort on the field trips has been devoted to evaluating the performance of solid-bowl conveyor-type centrifuges and imperforate-bowl basket-type centrifuges. Interpretation of the data obtained during these field trips is in progress but results are not yet available.

FUTURE WORK

In-house studies of dewaterability of phosphate sludges will be reduced in scope during the next fiscal year, although study of centrifugation of Al-primary sludges will be continued.

Work with the trailer will continue and will be expanded to include more dewatering devices than used in tests to date. Emphasis in the continuing work with the trailer will shift from phosphate removal sludges to a wider variety of sludge types, and to comparisons of performance of various types of dewatering equipment.

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EFFECTS OF CONTROL VARIABLES AND SLUDGE CHARACTERISTICS ON THE PERFORMANCE OF DEWATERING AND THICKENING DEVICES

by

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1 INTRODUCTION

In August 1971, the Government of Canada and the Government of the Province of Ontario signed an agreement to ensure that the water quality of the Great Lakes is restored and protected. This 'Canada-Ontario Agreement on Great Lakes Water Quality', was signed in response to recommendations of the IJC concerning pollution of the Lower Great Lakes and in anticipation of the Canada/United States Agreement on Great Lakes Water Quality. The Agreement specifies that nutrient (nitrogen, carbon and phosphorus) levels in waste treatment plant effluents should be drastically reduced, since these nutrients are considered essential elements for algal growth. Conventional treatment schemes for removing these elements will result in increased sludge production and may produce sludge characteristics which cause dewatering and ultimate disposal problems. As a result a provision was included in the agreement for research programs to examine these areas with a view to reducing the capital and operating costs required to achieve the specific water quality criteria set out.

The 'Sludge Treatment Process Development Program' which was initiated at this time was aimed at measuring sludge production, characterizing sludges with respect to their physical and chemical properties and correlating these properties with the efficiency of various sludge dewatering processes. Part II of the program was to examine the control variables and scale-up techniques of the following sludge dewatering processes: vacuum filtration, centrifugation, dissolved air flotation, gravity thickening and pressure filtration. The specific objectives were to evaluate the following:

1. measurement of sludge production and properties resulting from various chemical treatments for phosphorus removal;

2. assessment of sludge physical properties as indicators of dewatering and handling difficulty;

3. measurement of the effects of various chemical and mechanical conditioners on, (a) characteristic properties of sludges and (b) dewatering process control parameters;

4. assessment of various bench-scale sludge dewatering tests;

5. evaluation of dewatering devices at full or pilot-scale to assess the effect of control variables and sludge properties on performance;

6. development of scale-up methodology by correlating bench, pilot and full-scale dewatering test results.

This paper will address the latter three objectives. Two dewatering processes, centrifugation (solid bowl and imperforate basket) and dissolved air flotation are examined. Results will be presented on the effect of control variables and sludge type on unit performance. Similar studies are currently underway on vacuum filtration, plate and frame pressure filtration and gravity thickening.

2 DESCRIPTION OF EQUIPMENT AVAILABLE

To meet its objectives, the Wastewater Technology Centre has developed a sophisticated analytical laboratory for measuring physico-chemical properties, fabricated a mobile bench-pilot scale sludge dewatering facility and assembled a number of mobile pilot-scale dewatering units.

2.1 Analytical Laboratory Trailer

Laboratory services are provided for by a 30-foot long by 8-foot wide ACCO laboratory trailer. The unit is self-contained, requiring only a supply of electric power (230 volts/3 phase/30 amps) and fresh water (10 gmp). Equipment for most routine wastewater and sludge parameter measurements is available. The unit is also equipped with bench sludge testing equipment including: filter leaf test units, jar

test apparatus, a capillary suction time unit (CST), a batch air flotation unit, a laboratory centrifuge and penetrometer, a one-foot diameter, 8-foot long tube settling column, a one-foot diameter by 4-foot deep continuous thickener and a laboratory plate and frame pressure filter. For measurement of specific physico-chemical characteristics, there is a Haake Rotovisco RV-3 rotational viscometer, a Model T Coulter Counter, a Zeta Meter and a camera and microscope set-up.

2.2 Bench-Pilot-Scale Dewatering Facility

The bench-pilot scale sludge dewatering facility is housed in a Fruehauf Model F enclosed highway trailer van, 45 feet long by 8 feet wide. The unit is self-contained with respect to utilities requiring a supply of electric power (550 volt/3phase/30 amps), fresh water (20 gpm) and the sludge to be dewatered. The sludge handling equipment includes a 1362-l (300 I gal) sludge holding tank, a 22.7 to 136.2-l (5 to 30 I gal) sludge flocculation tank for mechanical conditioning and three 136.2-l (30 I gal) chemical storage tanks. Variable rate Moyno pumps are used for sludge pumping and Milton Roy variable stroke diaphragm pumps for sludge conditioning chemical flows. All storage tanks are equipped with variable speed agitators. There is also a piping system in the van which allows sludge and chemical conditioners to be introduced to or withdrawn from all process stages. The dewatering equipment includes the following:

(a) Sharples P-600 Super-D-Canter - This is a continuous scroll, solid bowl centrifuge and is capable of dewatering continuous sludge flows of up to 12.7 m^3/hr (10 I gpm). It is equipped with a 15.24 cm (6 inch) diameter cylindrical-conical bowl, a 5.08 cm (2 inch) pitch conveyor and internal polyelectrolyte addition features. Three bowl speeds of 4000, 5000 and 6000 rpm are available by selection of various pulley combinations and there is a variable speed backdrive unit for setting the differential speed between bowl and scroll. The pond depth may also be adjusted to one of several depths by selecting the proper dam plate;

(b) Sharples-Fletch Mark III Basket Centrifuge - This is a 35.56 cm (14 inch) diameter by 15.24 cm (6 inch) deep solid bowl or perforate basket vertical centrifuge with a batch continuous sludge processing capacity of up to 1.09 m^3/hr (4 Igpm). The bowl speed is infinitely variable from 500 to 3000 rpm. A manually adjustable skimmer is incorporated into the unit so that different depths of the inner surface of the sludge cake may be skimmed off.

(c) Komline-Sanderson Air Flotation Unit - This is a 0.093 m^2 (1 ft^2) surface area flotation zone type HR/SR-1 flotation unit with a sludge handling capacity of 0.82 m^3/hr (3 Igpm). The unit uses a pressurized effluent recycle system to provide the air for flotation. Effluent at 10.15 kN/m^2 (70 psig) is recycled to a retention tank where a reaeration pump recirculates the water and saturates it with air. The pressurized dissolved air water mixture then passes through a pressure reducing valve and is mixed with the feed sludge. Recycle flows of 10 to 500 precent of the feed sludge flow can be used. The floated sludge is removed by a manual skimmer. If chemicals are used in sludge conditioning they are added to the recycle stream just before it is mixed with the incoming feed sludge.

(d) Komline-Sanderson Mini-Filter - The mini-filter is a rotary vacuum drum filter, with a filtering capacity of 1.19 m^2 (42 ft^3) of air and up to 1.09 m^3/hr (4 Igpm) of sludge. The mini-filter drum, 45 cm in diameter with and 18.3 cm wide face (0.26 m^2 of filter area), consists of 16 drum compartments. This makes possible an accurately controlled cut-off point for applying or witholding vacuum or compressed air on the face of the drum. The drum has a variable speed drive providing drum speeds of 1 to 3 rpm.

(e) Sperry Pressure Filter - This is a 45.7 by 45.7 cm (18 by 18 inch) square plate and frame pressure filter which may operate at pressures up to 36.25 kN/m^2 (250 psig). The

sludge is dewatered in a batch-continuous process, with operating cycles ranging from 4 to 12 hours. The unit is provided with 12 center feed, pyramid surface, flush plates. The frames which form the cake chambers are available in two sizes, 2.54 and 5.08 cm thick. A 6-stage Moyno pump with an adjustable pressure control system capable of generating pressures of 58 kN/m^2 (400 psig) is used to feed the sludge.

2.3 Pilot-Scale Dewatering Units

The sludge dewatering equipment inventory also includes a number of pilot-scale units. These units have been made portable by providing each system with the following: a motor control center capable of supplying power via flexible plug-in electrical connections from equipment to motor control center, and flexible hose and quick disconnect fittings for all liquid flows to and from the equipment. Site requirements consist of a power supply (550 volts/3phase/60 amps) to the motor control center, and a source of fresh water and sludge. The sludge handling equipment includes 2270-1 (500 I gal) sludge holding tanks, 272, 568, and 1362-1 (60, 125 and 300-I gal) sludge flocculation tanks for mechanical conditioning, and a number of 1362-1 (300 I gal) chemical storage tanks. Controllable rate Moyno pumps with ranges of 0.027 to 8.18 m^3/hr (0.1 to 30 Igpm) are used for sludge flows and either Milton Roy variable stroke diaphragm pumps (flows up to 0.27 m^3/hr) or Hayward Gordon variable speed gear pumps (flows up to 0.82 m^3/hr) are used for the conditioning chemical flows. Tanks are equipped with variable speed agitator where required. An inclined screw conveyor is available for transporting dewatered sludge to disposal bins. The dewatering units include the following:

(a) Kruger K-500 Centrifuge - This is a continuous solid bowl conveyor centrifuge which is capable of dewatering sludge flows of up to 8.18 m^3/hr (30 Igpm). The bowl is completely conical with a maximum diameter of 50 cm and a speed of 1660 rpm. It is complete with facilities for adding conditioning chemicals within the bowl. Pond depth is adjustable to three separate levels by changing the overflow rings. Variation in the differential speed of the conveyor from 12

to 35 rpm is accomplished through the use of various pulley combinations.

(b) Komline-Sanderson Air Flotation Unit - This is a 1.39 m^2 (15 ft^2) flotation zone type flotation unit with a sludge processing capacity of 5.45 m^3/hr (20 Igpm). Recycled effluent is saturated with air in the retention tank at a pressure of 10.15 kN/m^2 (70 psig) and mixed with the incoming sludge feed. Recycle flows of 1.36 to 13.6 m^3/hr (5 to 50 Igpm) are available. Sludge is removed with a skimmer operating either continuously or on a timed on-off cycle. Associated with the unit is a 1816-1 (400 I Gal) mechanical flocculator equipped with a 4 paddle variable speed agitator. Provision is made for the addition of polyelectrolyte to either the flocculator or the recycle stream of the air flotation unit.

(c) Eimco Vacuum Filter - This unit is a rotary drum vacuum filter, with a filtering capacity of 11.4 m^3 (400 ft^3) of air and up to 1.09 m^3/hr (4 Igpm) of sludge. The filter drum 0.914 m (3 feet) diameter by 0.305 m (1 foot) wide [0.88 m^2 (9.4 ft^2) of filter area], consists of 20 drum compartments. Form and dry time may be altered by blocking specific drum compartments. The drum has a variable speed drive providing drum speeds of 0.5 to 5 rpm. Drum submergence may be varied by adjusting the height of the pit overflow pipe.

(d) Eimco Gravity Thickener - This unit is a conventional center feed circular thickener with a surface area of 1.82 m^2 (19.625 ft^2) and a sidewall depth of 1.35 m (4.43 ft). The rake speed is variable from 0.25 to 1.0 rpm through the use of alternative chain drive sprokets.

3 THEORY AND DESIGN METHODS

3.1 Solid Bowl Conveyor Centrifuge

The basic elements of a centrifuge consist of a method of intro-

ducing the feed slurry, a zone where solid liquid separation occurs under an applied force and a means of discharging the clarified effluent and dewatered solids. In the solid bowl conveyor centrifuge the feed sludge is introduced at the center of a spinning bowl. The solids settle outwards forming a layer at the bowl wall. The liquid (centrate) remains at the center of the bowl and is discharged by gravity over a weir or removed by a skimmer. The solids at the bowl wall are removed by a scroll conveyor which is rotating at a slightly different speed to that of the bowl.

Centrifuge performance factors may generally be classified as those which are fixed in the design of a particular machine and those which can be adjusted during operation. The first group includes bowl configuration (conical, cylindrical-conical), length to diameter ratio of the bowl, beach angle and length, and scroll configuration (number of flights and pitch). The second group includes sludge pool volume, bowl rotational speed (centrifugal force), scroll differential speed, sludge feed rate, polyelectrolyte dosage, and point of polyelectrolyte addition. Although this latter group contains both machine and process variables they are grouped together and referred to as control variables. The relative importance of these variables is largely dependent upon the characteristics of the sludge being centrifuged.

The most widely used method of sizing a full-scale centrifuge has been to scale-up the results from a geometrically similar pilot-scale unit using the Sigma theory. The parameter Sigma (Σ) contains only the characteristics of the centrifuge and may be defined as:

$$\Sigma = \frac{V\omega^2}{g \ln \frac{r_2}{r_1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where V = pool volume

ω = rotational speed of the bowl

r_2 = radius of the centrifuge bowl

r_1 = radius to the inner surface of the liquid layer in the bowl

g = gravitational constant

If the liquid flow rate through a centrifuge is designated by Q, the Sigma concept states that two geometrically similar but different sized machines will have the same performance for a given slurry, when the ratio Q_i / Σ_i for both machines are equal, that is:

$$\frac{Q}{\Sigma_1} = \frac{Q}{\Sigma_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Alternately, if the percent solids recovery is plotted against Q/Σ on log-probability paper, all performance data for geometrically similar machines will fall on one straight line.

This Sigma concept which was developed by Ambler (1), has been extensively analyzed by Vesilind (2) and Schultz (3). Vesilind (2) points out that the Sigma concept for scale-up is valid only when the centrifuge performance is liquid capacity limiting. Where solids capacity is limiting the Sigma concept breaks down. As a result Vesilind has developed an alternative method of scale-up using a Beta factor. Again Beta (β) is a function of machine variables and is defined as:

$$\beta = SN\pi DP \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where S = spacing between conveyor blades
N = the number of leads
D = bowl diameter
P = pool depth

In a similar manner to that employed for the Sigma concepts, two geometrically similar but different sized machines will have the same performance for a given slurry when;

$$\frac{Qs}{\beta_1} = \frac{Qs}{\beta_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where Qs is the solids flow rate. Systems involving sewage sludges are far from ideal. As a result both the Sigma and Beta concepts have severe limitations. However, where possible, it is suggested that scale up be conducted using both methods and the limiting one used for design purposes (2, 5).

When data from geometrically similar machines is not available, laboratory tests may be used to predict the performance of a centrifuge.

Measurements of samples spun on a laboratory centrifuge have been correlated to actual centrifuge performance by Vesilind (4) using simple regression analysis. The model used encompasses both sludge settling and scrolling properties and includes three terms - the feed solids concentration, the centrate concentration and the cake concentration. The scrolling property is measured by a penetration test.

3.2 Basket Centrifuge

A basket centrifuge employs a rotating vertical bowl with a lip ring. Feed is introduced at the center of the base and as it flows upward the solids settle out into a cake at the bowl wall. The clarified effluent overflows the lip ring at the top and discharges by gravity. No provision is made for sludge cake removal during operation. When the sludge cake has accumulated to the edge of the lip ring or when centrate quality has deteriorated below a predetermined level, the feed is interrupted and the softer liquid interior surface of the cake skimmed off while the bowl is still rotating at full speed. The bowl speed is then reduced to approximately half-speed and the remaining compacted solids are cut out using a stationary advancing knife. The bottom of the bowl opens simultaneously to allow discharge of the solids.

The geometry of the bowl, the method of feed introduction and the method of solids and centrate removal are fixed in the design of the machine. The variables which can be adjusted during operation include sludge feed rate, bowl speed (centrifugal force) and polymer addition.

Full-scale basket centrifuges may be sized using the Sigma concept, previously discussed, to scale-up from data obtained on a geometrically similar pilot-scale test unit. The value of Sigma for a basket centrifuge can be calculated using the following formula (6):

$$\Sigma = 2\pi l \frac{\omega^2}{g} \left(3/4\ r_3^2 + 1/4\ r_1^2\right) \quad \ldots\ldots (5)$$

where l = height of the bowl

ω = angular velocity of the bowl

g = acceleration of gravity

r_3 = bowl radius

r_1 = radius to inner surface of liquid layer

As stated earlier, scale-up is based on the fact that two geometrically similar but different sized machines will have the same performance for a given slurry when the ration $(Q/\Sigma)_i$ for both machines are equal, that is;

$$\frac{Q}{\Sigma_1} = \frac{Q}{\Sigma_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The system is again subjected to several non-ideal conditions. In the case of a basket centrifuge further complications are introduced because the effective volume of the bowl decreases with time. Thus, this scaling procedure should be applied with caution. At least one manufacturer (7) has formulated a mathematical model to account for the inherent deficiencies of the system. The model is then subjected to a computerized trial and error solution.

3.3 Dissolved Air Flotation

Dissolved air flotation is a very pratical technique for separating suspended particles and colloidal materials from liquids. By attaching air bubbles to the suspended particles until their combined net specific gravity becomes less than that of water, the particles are made buoyant. These buoyant particles then rise quickly to the surface forming a 'float' which can be removed by skimming. To produce the microscopic air bubbles required for effective flotation, air is added to a solid suspension and the mixture elevated to a high pressure [5.8 - 13.1 kN/m^2 (40-90 psig)]. Since the solubility of air increases with pressure, the air dissolves. For example, at 5.8 kN/m^2 about five times more air can be dissolved in water than at atmospheric pressure. Subsequently, when pressure is released, the liquid becomes supersaturated and the volume of air in excess of the atmospheric saturation concentration comes out of solution in the form of microscopic bubbles. These bubbles may range in size from 30 to 120 microns, depending on factors such as the type of release, pressure, presence of chemicals, etc. (8).

Recent advances in the design of air flotation thickeners have overcome most of the difficulties experienced in early designs, the most common of which was the disintegration of sludge particles in the recycle system to create small hard-to-remove particles. The use of flotation

aids and polyelecyrolytes has alleviated these difficulties. The design of the inlet mixing chamber and the point of addition of flotation aids are highly significant, the best results being obtained when flotation aids are introduced in the recycle line immediately before the pressure release valve. Although the performance of a flotation unit is affected by variables such as the method of introducing the pressurized liquid to the flotation zone and the method of dissolving the air in the recycle, these variables are normally fixed in the physical design. Variables which may be adjusted during operation include the following: solids loading to the unit (kg of solids/m^2/hr), saturation pressure (atm) and polymer dosage (kg of polymer/kg of solids).

The normal procedure used in sizing flotation units is based on the air-solids ratio. When pressurized recycle is used, the air/solids ratio can be computed by the following equation:

$$\frac{A}{S} = \frac{K\, s_a\, R(fP-1)}{Q\, S_a} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

where: A/S = air to solids ratio (weight basis)

K = constant particular to the units used (K = 1.3 for the units used)

s_a = air saturation in retention tank, cm^3/l

R = pressurized recycle, m^3/hr

f = fraction of saturation of air in the recycle

P = absolute pressure, atm

Q = waste flow, m^3/hr

S_a = influent suspended solids, mg/l

In practice, the optimum air/solids ratio is determined from laboratory experiment by developing relationships between the air/solids ratio and effluent suspended solids and float solids. With this optimum air/solids ratio, the required recycle rate may be obtained from equation 6. The surface area of the unit is then determined using the total flow and an accepted value for the overflow rate. Acceptable overflow rates which have been developed from experience at many installations range from 140 to 280 m^3/m^2 day (2 to 4 Igpm/ft^2) (9). Units may also be sized on the basis of solids loading. Again, accepted values based on past experience are used. The range suggested by one manufacturer is 586 to 878 kg/m^2 day

(2 to 3 lbs of dry solids/ft^2hr) (10). The maximum area determined on the basis of solids and liquid loading should be used for design.

4 SLUDGE SOURCES

The sludges examined in this study were obtained from the following treatment plants: the extended aeration pilot plant at the Wastewater Technology Centre, the Town of Tillsonburg Sewage Treatment Plant and the City of Hamilton Sewage Treatment Plant.

4.1 Extended Aeration Pilot Plant - Wastewater Technology Centre

The extended aeration pilot plant at the Wastewater Technology Centre was operated at its design flow of 4.54 m^3/hr (20 Igpm) giving a detention time of 24 hours in the aeration compartment. Oxygen was supplied by a diffused air system. The clarifier detention time was 3.8 hours and had a surface loading rate of 8.48 m^3/m^2/day (250 Igal/ft^3/day). Sludge was wasted intermittently to maintain a mixed liquor suspended solids concentration of approximately 4000 to 5000 mg/l. The solids concentration of the waste sludge ranged from 0.95 to 1.4%. Incoming feed to the plant consisted of raw sewage from the City of Burlington having an average BOD_5 of 150 mg/l and a suspended solids concentration of 240 mg/l. Removals of 95% or better were normally achieved for both BOD_5 and suspended solids. Sludge was obtained from this plant while it was operating without chemical addition for phosphorus removal (baseline), with the addition of 133 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$ and with the addition of 15 mg/l of ferric ion. The alum was added as a liquid solution to the transfer pipe between the aeration tank and the clarifier, while the ferric ion was added as a solution of ferric chloride at the head end of the aeration tank.

4.2 City of Hamilton Sewage Treatment Plant

The Hamilton Sewage Treatment Plant is a conventional activated sludge plant with a design capacity of 190,000 m^3/day (60 Imgd). Grit removal and primary sedimentation are provided before the aeration basin. At design flow, the aeration system has a retention time of 5.0 hr and a mixed liquor suspended solids concentration of 2000 mg/l. Oxygen requirements are provided by mechanical aeration. The secondary clarifier retention time was 2.9 hr at an overflow rate of 18.32 m^3/m^2/day (520 Igal/

ft^2/day). The concentration of the waste activated sludge used for this study ranged from 1.3 to 3.0%.

4.3 Town of Tillsonburg, Water Pollution Control Plant

The Tillsonburg Sewage Treatment Plant is a conventional activated sludge plant with a design capacity of 5673 m^3/day (1.8 Imgd). Phosphorus removal is accomplished by the addition of 138 mg/l of alum to the mixed liquor in the aeration tanks. The waste activated sludge and primary sludge are reduced by anaerobic digestion in a single-stage digester. The digester detention time was approximately 38 days. Digested sludge received from the plant ranged from 2.5 to 4.5% solids.

5 RESULTS

5.1 Solid Bowl Centrifugation

Tests were carried out using the Sharples P-600 Super-D-Canter and the Kruger K-500 centrifuges. Four sludges were used. These include waste activated sludge from the extended aeration plant at the Wastewater Technology Centre, sludge with 133 mg/l of alum added for phosphorus removal from the same treatment plant, waste activated sludge from the Hamilton Sewage Treatment Plant and digested alum sludge from the Tillsonburg Sewage Treatment Plant. Each centrifuge was not tested with all sludges, nor were all control variables investigated with each sludge or machine. Trends reported are typical unless specified otherwise. Polymer dosage was defined as kg of polymer per metric ton of dry solids in the feed and polymer quantities are reported in terms of the active ingredient. This compensates for liquid polymer which may contain only 20 to 40% by weight of active polymer.

The accepted measures of centrifuge performance are: quality of the centrate and moisture content of the discharged cake. These measures are normally expressed as solids recovery (%) and solids content of the cake (%). The solids recovery was calculated using the following formula:

$$R = \frac{K\ (F - C)}{F\ (K - C)} \times 100 \quad \ldots\ldots\ldots\ldots\ (7)$$

where R = solids recovery (%)

K = solids in the cake (%)

F = solids in the feed sludge (%)

C = solids in the centrate (%)

which accounts for the liquid in the discharged cake.

The amount of polymer used an an aid in the separation process is an important variable in centrifuge operation because it normally accounts for 50 percent of the operating costs. As a result, polymer requirements were examined in detail. Increasing polymer dosages resulted in increased solids recovery for all sludges tested. The range of polymer dosages for which acceptable performance was achieved depended on the sludge studied. This effect is illustrated in Figure 1 for three different sludges. Cake solids concentrations were not as sensitive to polymer dosage as the solids recovery and the effect depended upon the sludge studied. Waste activated sludge (WTC-baseline) showed an increase in cake solids with increased polymer dosage while waste activated sludge (WTC-133 mg/l alum and Hamilton) and digested alum sludge showed no definite trend.

A variable frequently overlooked in centrifuge studies is the magnitude of the polymer solution flow rate with respect to the sludge feed rate. This variable was investigated with waste activated sludge (WTC-baseline) in the P-600 centrifuge. The results of this experiment are shown in Figure 2 and indicate an optimum rate of 10% or less from both solids recovery and cake solids considerations. These results agree with the data presented by Schultz (3) who found 10% to be optimum for the primary, waste activated, and digested sludge he tested.

Increasing the centrifugal force did not increase the clarification of waste activated sludge (WTC-baseline) or digested alum sludge (Tillsonburg). An increase in the centrifugal force from 1360 x G to 2160 x G yielded lower solids removals in all cases. Although some overlapping of the results in cake solids occurred, they tended to be higher at the higher centrifugal force. The increased centrifugal force had a much greater effect on the waste activated sludge (WTC-baseline) than the digested sludge (Tillsonburg), however this may have resulted from the lower pond depth used for the waste activated sludge.

The effect of pond depth on performance with waste activated sludge (133 mg/l Alum) is illustrated in Figure 3. This control variable cannot be adjusted to optimize both performance parameters simultaneously. Although the deeper pond significantly improved the solids recovery, a substantially wetter cake was discharged as a result.

The prediction of full-scale centrifuge performance may be

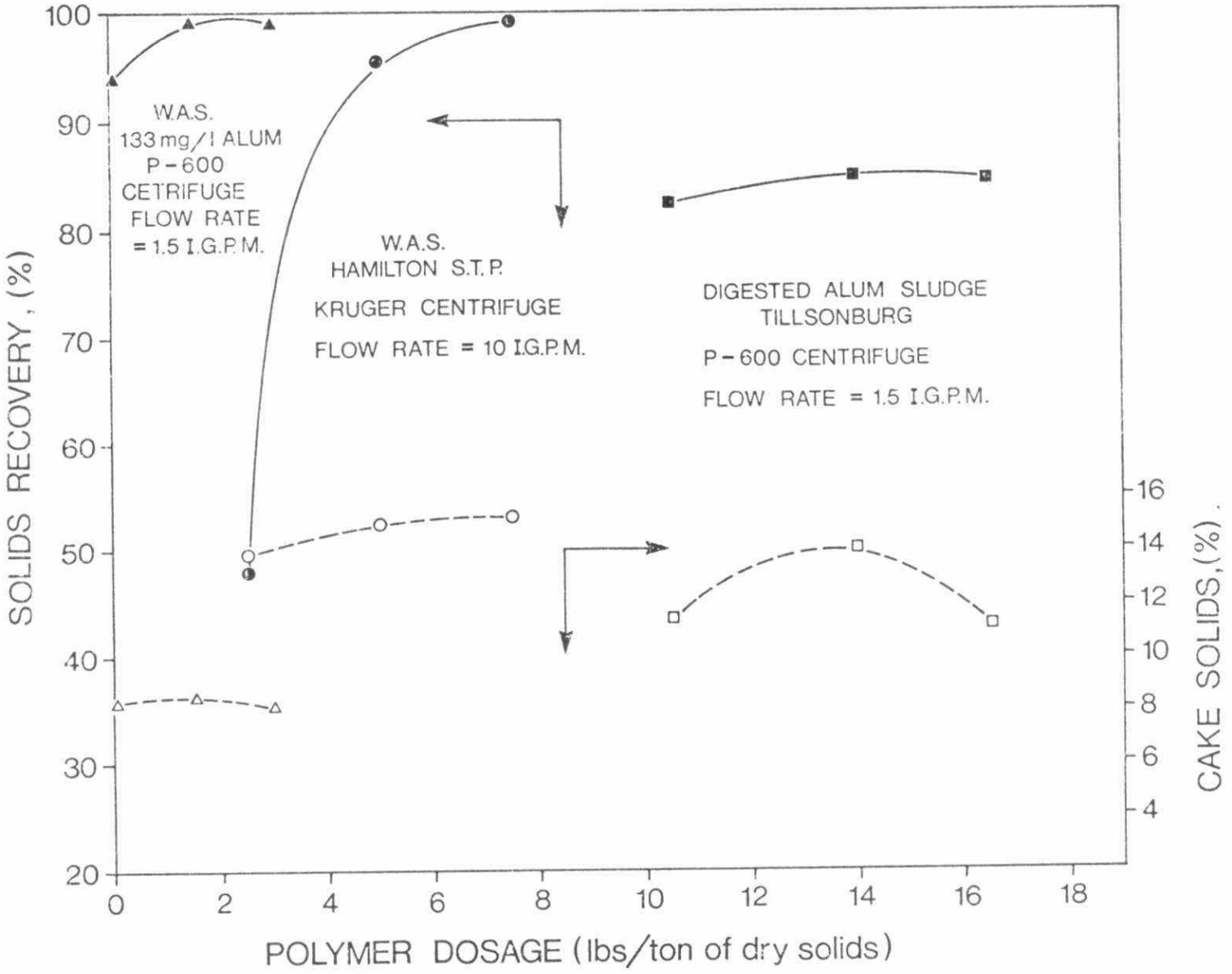

FIGURE 1. EFFECT OF POLYMER DOSAGE ON THE PERFORMANCE OF THE SHARPLES P-600 AND KRUGER K-500 CENTRIFUGES.

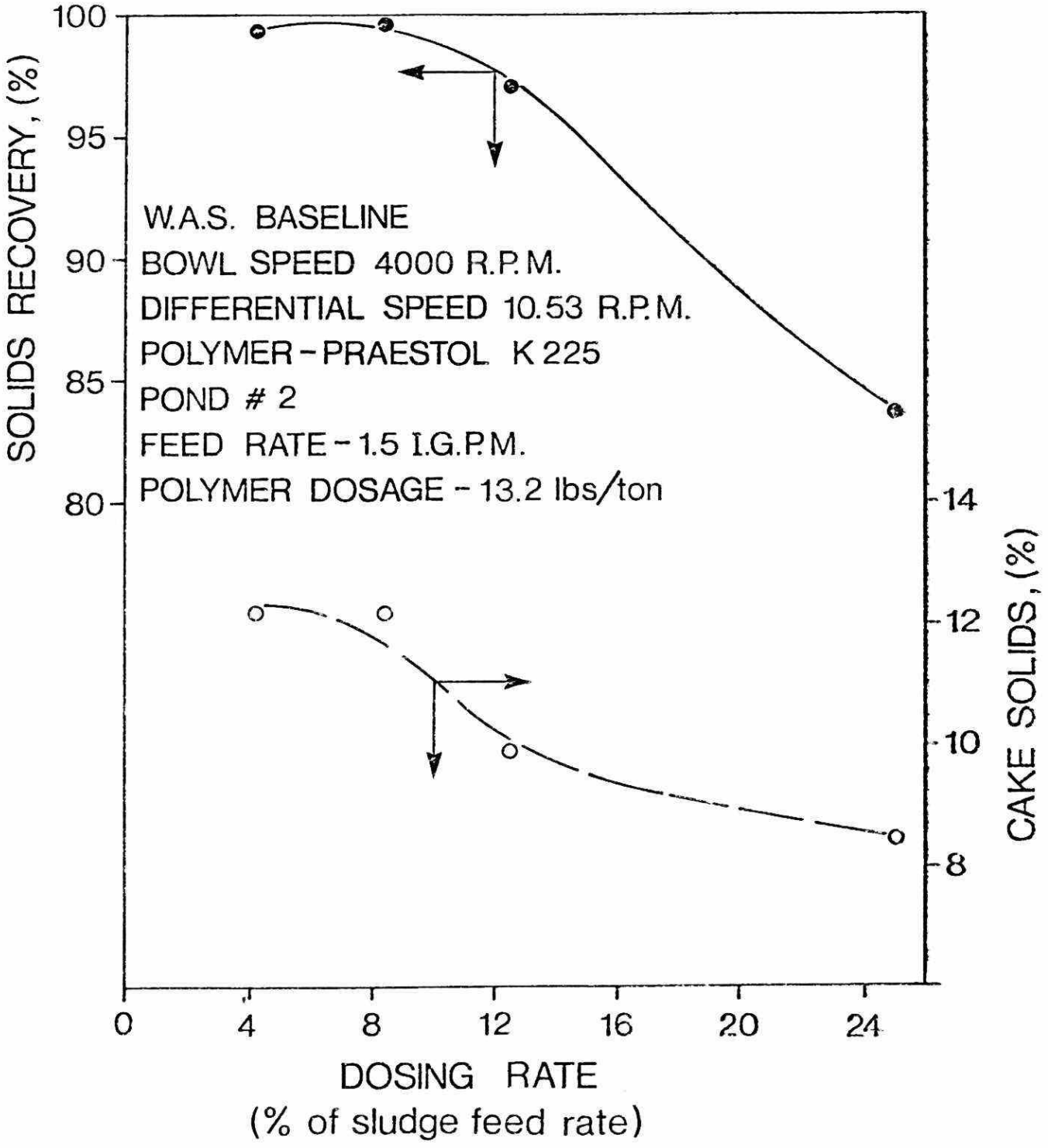

FIGURE 2. EFFECT OF POLYMER DOSING RATE ON THE PERFORMANCE OF THE SHARPLES P-600 CENTRIFUGE.

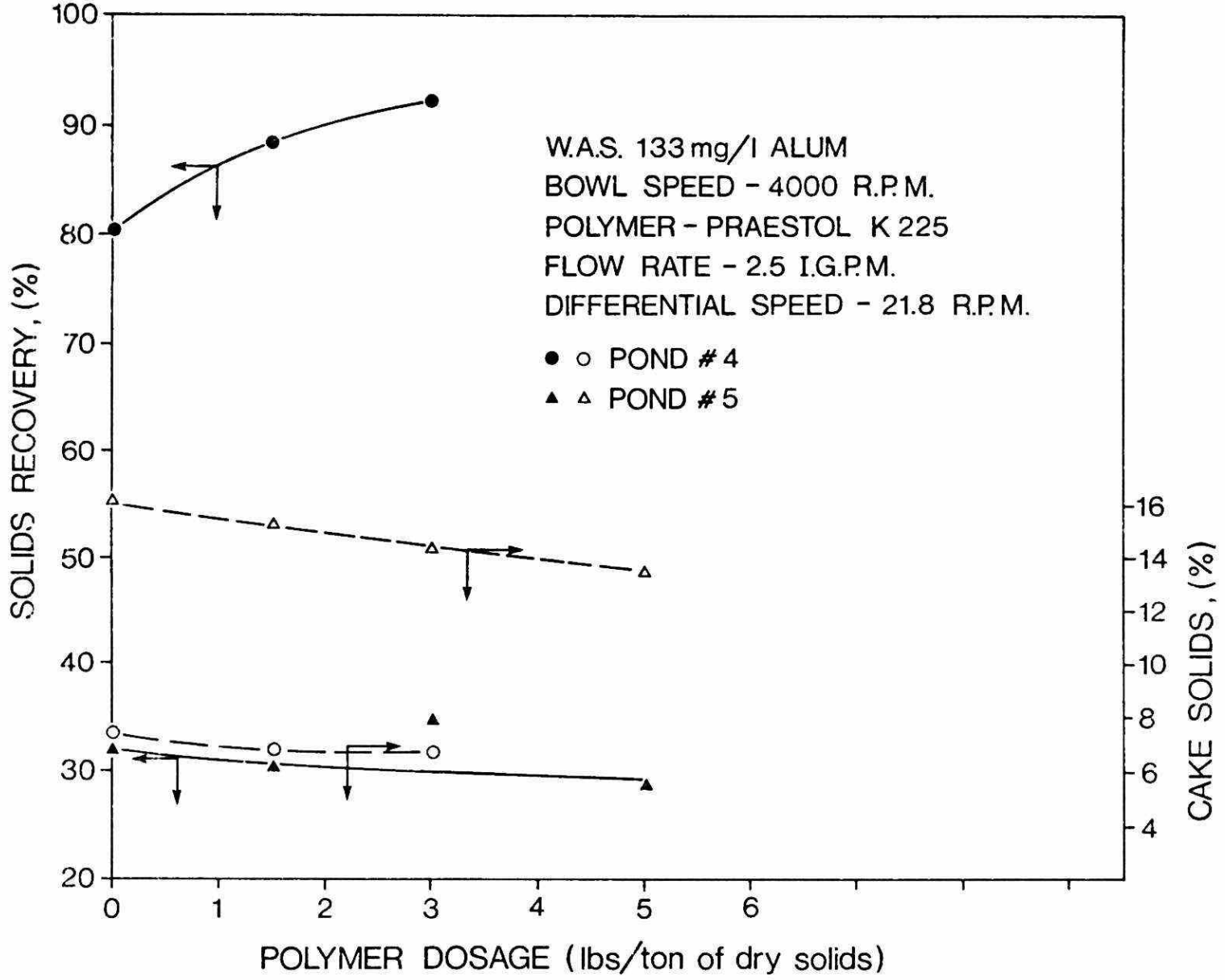

FIGURE 3. EFFECT OF POLYMER DOSAGE AND POND DEPTH ON THE PERFORMANCE OF THE SHARPLES P-600 CENTRIFUGE.

accomplished by using data from laboratory tests or from smaller geometrically similar machines. The latter method is preferred as a greater degree of confidence is generally possible. Most of the data obtained in this work were hydraulically limiting. Generally an increase in liquid flow rate results in a decrease in recovery efficiency. At these low solids loadings, the differential speed between the scroll and the bowl had little effect on solids recovery, except that unwanted turbulence may have been introduced redispersing settled fines. However, as the solids loadings were increased, the differential speed became more critical. Figure 4 illustrates this effect, with increased solids loading the differential speed had to be increased to maintain solids recovery. In Figure 5, the two curves with similar solids loadings of 73 and 86 kg/hr (160 and 190 lbs/hr) exhibit much better correlation than the curves at similar hydraulic flow rates. In these cases, the solids removal is limiting and the 'Beta' concept should be used in scale-up. Values for Sigma and Beta for both centrifuges for two different sludges are presented in Table 1. In almost all cases within a sludge-centrifuge group recovery decreases with increasing Sigma and Beta. However, if comparisons are made between groups, it appears that solids removal is limiting in the case of the Kruger centrifuge. Thus, an increase in recovery could probably be obtained by increasing the scroll speed. For the P-600 runs, no limiting condition can be determined.

5.2 The Basket Centrifuge

Four sludges were used in the study on the Sharples/Fletcher Mark III Basket Centrifuge. They included waste activated sludge from the extended aeration plant at the Wastewater Technology Centre (baseline, with 133 mg/l of Alum and with 15 mg/l of Ferric iron) and digested alum sludge from the Tillsonburg Sewage Treatment Plant. Polymer addition, when applicable, was made into the feed sludge line prior to discharge into the centrifuge bowl. Centrate was sampled at regular intervals and the operating cycle terminated when centrate quality deterioration was visually observed. Instantaneous solids removal was calculated using the following formula:

$$\text{Solids Recovery (\%)} = \frac{\text{Feed Solids (\%)} - \text{Centrate Solids (\%)}}{\text{Feed Solids (\%)}} \times 100 \quad . \quad . \quad (8)$$

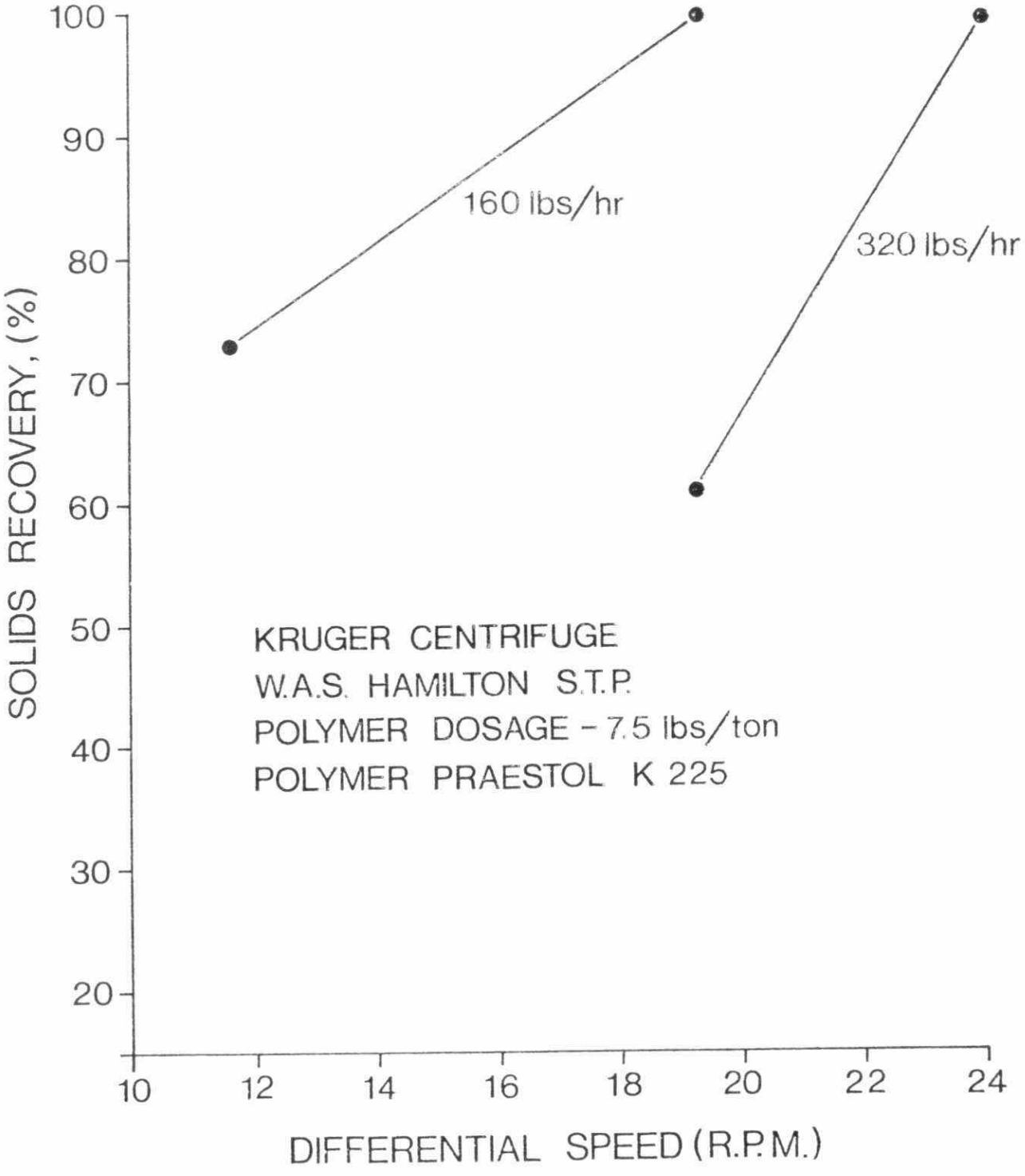

FIGURE 4. EFFECT OF DIFFERENTIAL SPEED AND SOLIDS LOADING ON THE PERFORMANCE OF THE KRUGER K-500 CENTRIFUGE.

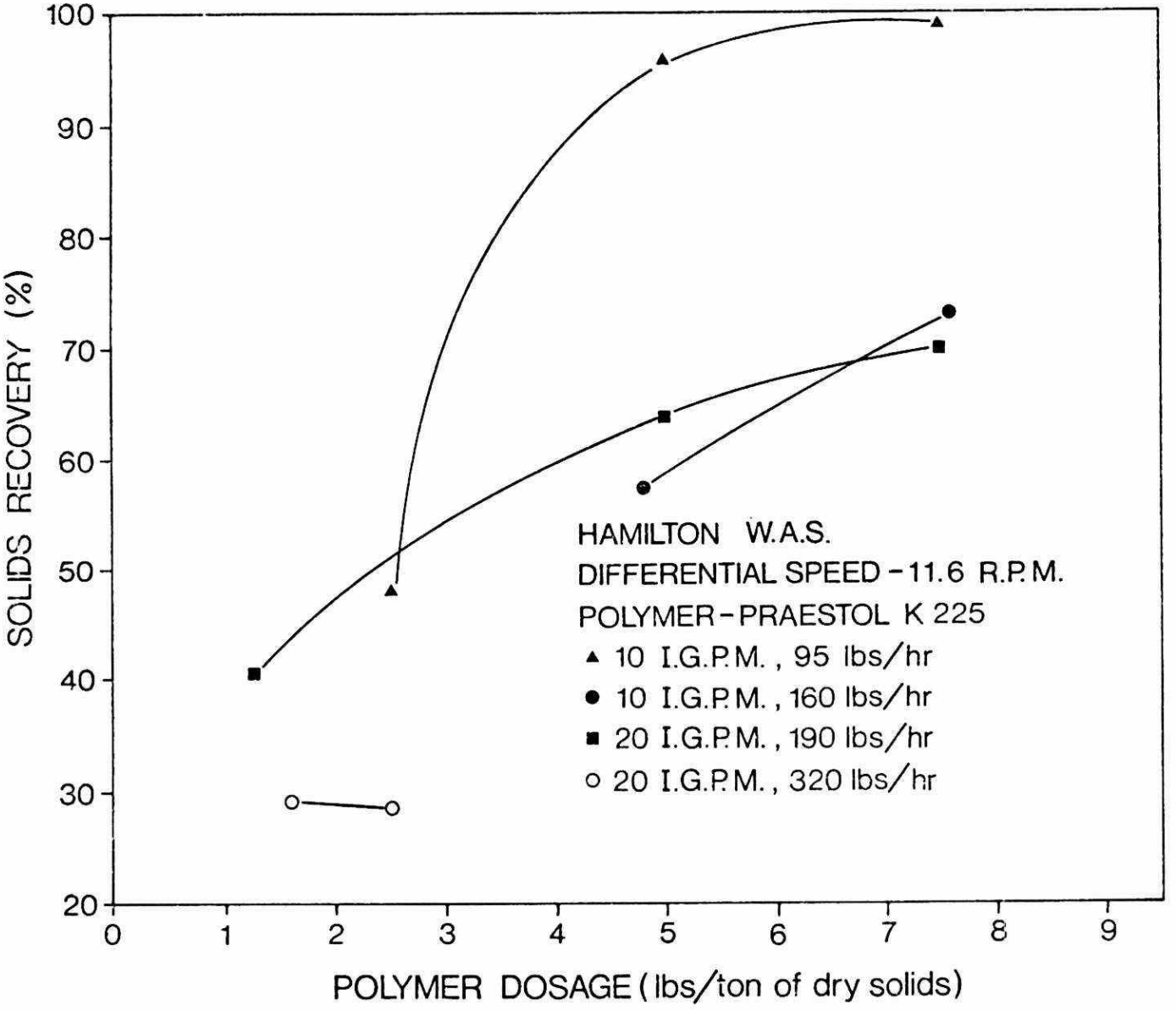

FIGURE 5. EFFECT OF POLYMER DOSAGE, SLUDGE FEED RATE AND SOLIDS LOADING ON THE PERFORMANCE OF THE KRUGER K-500 CENTRIFUGE.

TABLE 1. P-600 AND KRUGER CENTRIFUGE PERFORMANCE AS A FUNCTION OF SIGMA AND BETA FACTORS

Centrifuge	Bowl Dia. cm	Cent. Force XG	Pond Depth	Diff. Speed rpm	Polymer Dose Kg/ton	Σ cm^2	Q cm^3/sec	Q/Σ cm/sec	β cm^3/sec	Q_s Kg/sec	Q_s/β	% Recovery
					DIGESTED ALUM SLUDGE (TILLSONBURG)							
P-600	15.2	1360	4	10.5	8.3	10.77×10^5	38	3.52×10^{-5}	$.02 \times 10^4$	1.7×10^{-3}	0.85×10^{-5}	99.9
P-600	15.2	1360	4	10.5	8.3	10.77×10^5	114	10.55×10^{-5}	$.02 \times 10^4$	5.1×10^{-3}	2.54×10^{-5}	91.2
					DIGESTED ALUM SLUDGE (TILLSONBURG)							
KRUGER	50	770	Deep	11.6	8.3	88.3×10^5	568	6.43×10^{-5}	1.22×10^4	25.5×10^{-3}	0.21×10^{-5}	45.6
KRUGER	50	770	Deep	11.6	8.3	88.3×10^5	758	8.58×10^{-5}	1.22×10^4	34.0×10^{-3}	0.28×10^{-5}	43.1
KRUGER	50	770	Deep	11.6	8.3	88.3×10^5	947	10.72×10^{-5}	1.22×10^4	42.5×10^{-3}	0.35×10^{-5}	28.7
KRUGER	50	770	Deep	11.6	8.3	88.3×10^5	1137	12.88×10^{-5}	1.22×10^4	51.0×10^{-3}	0.42×10^{-5}	20.9
					WASTE ACTIVATED SLUDGE (HAMILTON)							
P-600	15.2	1360	4	10.5	3.75	10.77×10^5	38	3.52×10^{-5}	$.02 \times 10^4$	0.7×10^{-3}	0.35×10^{-5}	99.8
P-600	15.2	1360	4	10.5	3.75	10.77×10^5	190	17.64×10^{-5}	$.02 \times 10^4$	3.5×10^{-3}	1.75×10^{-5}	99.6
					WASTE ACTIVATED SLUDGE (HAMILTON)							
KRUGER	50	770	Deep	11.6	3.75	88.3×10^5	758	8.58×10^{-5}	1.22×10^4	12.04×10^{-3}	$.098 \times 10^{-5}$	99.9
KRUGER	50	770	Deep	11.6	3.75	88.3×10^5	758	8.58×10^{-5}	1.22×10^4	20.13×10^{-3}	$.165 \times 10^{-5}$	73.0
KRUGER	50	770	Deep	11.6	3.75	88.3×10^5	1516	17.17×10^{-5}	1.22×10^4	24.08×10^{-3}	$.197 \times 10^{-5}$	69.7
KRUGER	50	770	Deep	24.0	3.75	88.3×10^5	1516	17.17×10^{-5}	2.51×10^4	40.27×10^{-3}	$.160 \times 10^{-5}$	99.5

Average cake solids in the bowl was calculated by the following procedure. The volume of liquid sludge discharged through the manual skimmer was measured and a solids determination carried out (skim solids). The thickness of the layer of sludge remaining in the bowl was measured, the volume calculated and a solids measurement done (knife solids). The average cake solids was then calculated according to:

$$\text{Average Cake Solids (\%)} = \frac{\text{Skim Solids(\%) x Skim Vol.(l) + Knife Solids(\%) x Knife Vol.(l)}}{\text{Skim Volume (l) + Knife Volume (l)}} \quad \ldots\ldots\ldots\ldots (9)$$

The performance of a basket centrifuge may be described in terms of the effluent quality, the moisture of the cake and the length of the operating cycle under which a specified solids removal may be maintained. These parameters were examined for the four sludges at various levels of the machine control variables (centrifugal speed, sludge feed rate and polymer dosage).

The effluent quality during the operating cycle was a function of centrifugal force (bowl speed). Figure 6 indicates increased recovery at all operating times with increasing bowl speed. The addition of a polymer flocculated the difficult to separate fines and improved recovery (Figure 7). Increased feed rate decreased the residence time within the bowl and the recovery of suspended solids (Figure 8) in all cases.

The length of the operating cycle increased with increased centrifugal force (Figure 6), decreased feed rate (Figure 8) and increased polymer dosage (Figure 9). The termination of a cycle occurred when the bowl became filled with sludge and no space remained for sedimentation to occur. At a higher feed rate the solids flow to the unit is increased and thus the bowl filled in less time. A similar result was observed when the feed solids was increased at the same flow rate. The length of operating cycle for the alum digested sludge (feed solids 4.38%) was considerably less than that for waste activated sludge (feed solids 1.25%) at the same flow rate, centrifugal force and polymer dosage.

The cake solids increased with increasing centrifugal force and increased polymer dosage (Figure 10) but decreased with increased feed rate (Figure 11 and 12). The type of chemical treatment the activated

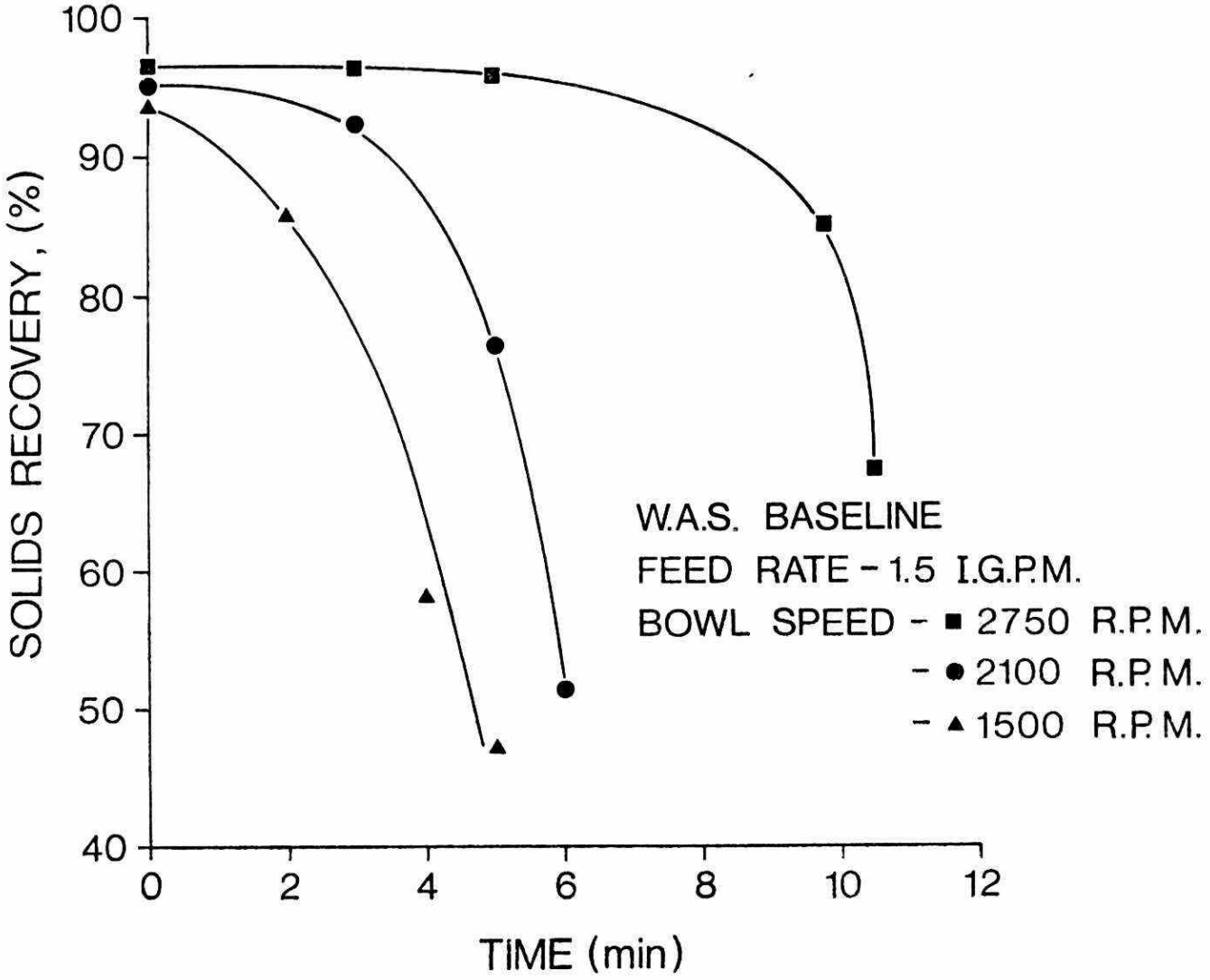

FIGURE 6. EFFECT OF BOWL SPEED (CENTRIFUGAL FORCE) ON SOLIDS RECOVERY FOR THE SHARPLES/FLETCHER MARK III CENTRIFUGE.

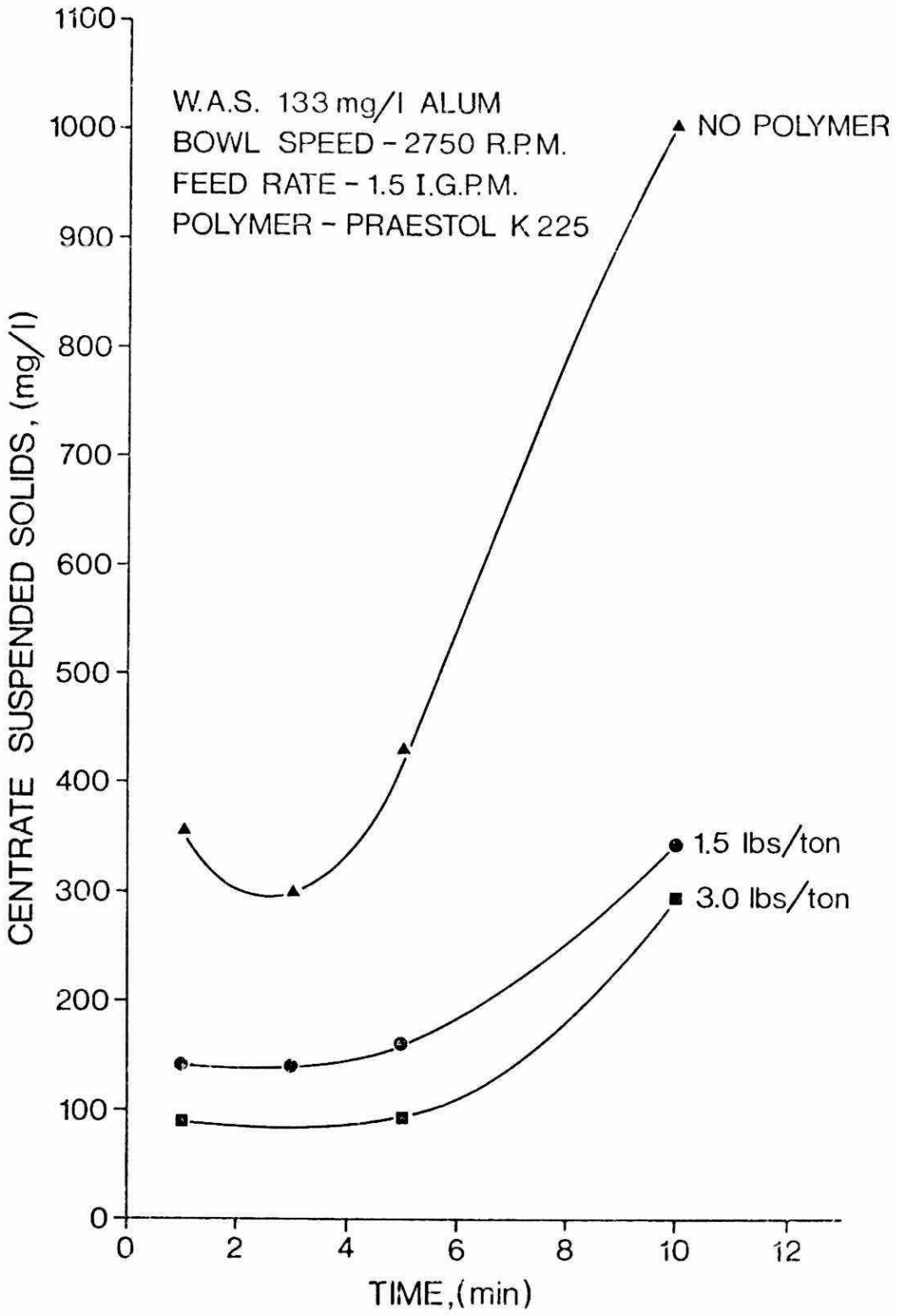

FIGURE 7. EFFECT OF POLYMER DOSAGE ON CENTRATE QUALITY FOR THE SHARPLES/FLETCHER MARK III CENTRIFUGE.

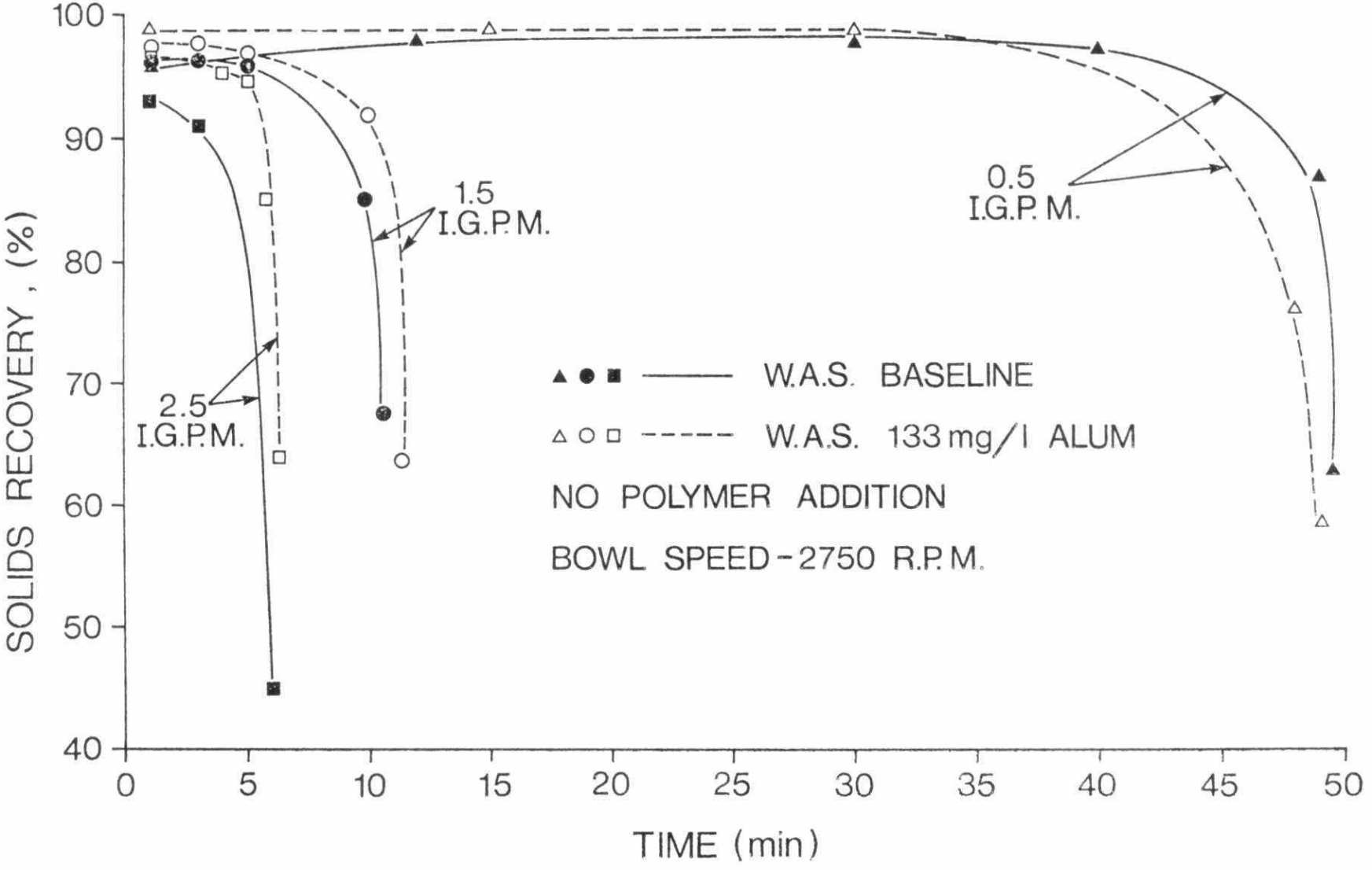

FIGURE 8. EFFECT OF SLUDGE FEED RATE AND TYPE OF SLUDGE ON SOLIDS RECOVERY FOR THE SHARPLES/FLETCHER MARK III CENTRIFUGE.

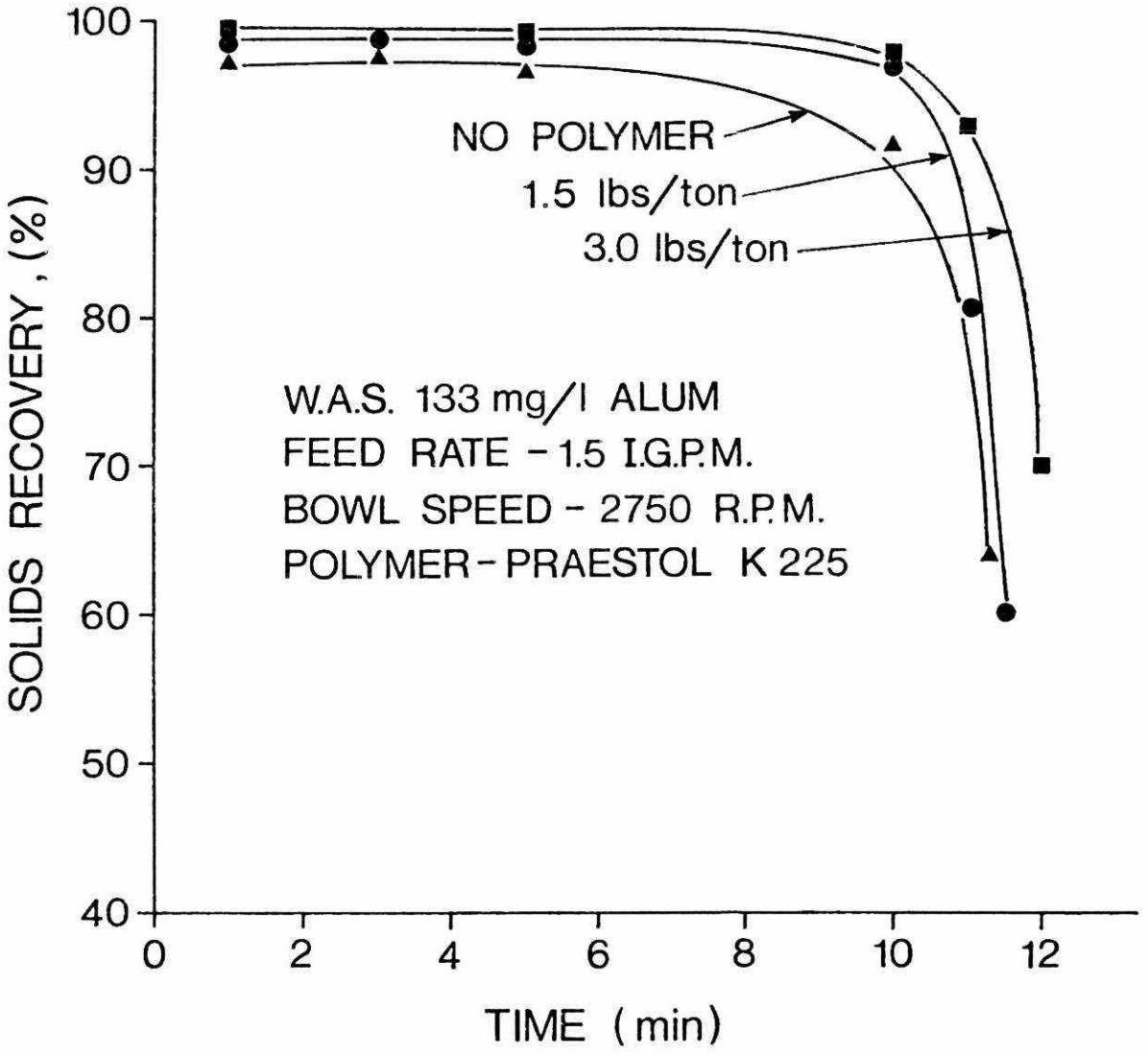

FIGURE 9. EFFECT OF POLYMER DOSAGE ON SOLIDS RECOVERY FOR THE SHARPLES/ FLETCHER MARK III CENTRIFUGE.

sludge was previously subjected to had an effect on the cake solids concentration (Figure 11). A similar trend was observed in the underflow concentrations from 24-hour settling tests using the same three sludges. Cake solids was not necessarily a function of the feed solids concentration as evidenced by Figure 12 where the cake resulting from a feed at 4.38% was less concentrated than that from a feed at 1.25%.

The performance of the basket centrifuge on four different sludges without the addition of polymer can be illustrated by a sedimentation performance curve (Figure 13). The solids recoveries reported are overall recoveries for the entire operating cycle. As expected, some decrease in clarity resulted from increasing through-put. The performance for all types of waste activated sludge was superior to that for the digested sludge. In practice, the solids recovery for a given through-put would probably be higher than the values shown in Figure 13 as the operating cycle would probably be terminated at a lower centrate suspended solids concentration.

5.3 Dissolved Air Flotation

Air flotation experiments were carried out on a batch flotation unit similar to that described by Eckenfelder and Ford (9) and on a $0.092m^2$ ($1\ ft^2$) and $1.39m^2$ ($15\ ft^2$) Komline-Sanderson continuous air flotation unit. Waste activated sludge from the Hamilton Sewage Treatment Plant was used for all tests. Polymer was added directly to the continuous units without the use of flocculator. The degree of saturation of air in the recycled effluent was 92.5% for all units. Air to solids ratio was calculated using Equation 6. Solids recovery was calculated using Equation 7 with the substitution of float solids instead of centrate solids.

The objective of this study was to compare the performance of the three test units, in terms of float solids concentration and effluent quality, with that of the full-scale $37m^2$ ($400\ ft^2$) units in operation at the Hamilton Sewage Treatment Plant. The operating conditions were similar to those used on the full-scale units. The effect of control variables on the performance of each unit was then studied by varying the air to solids ratio, the solids loading and the polymer dosage. The effect of control variables was difficult to ascertain due to the limited operating range

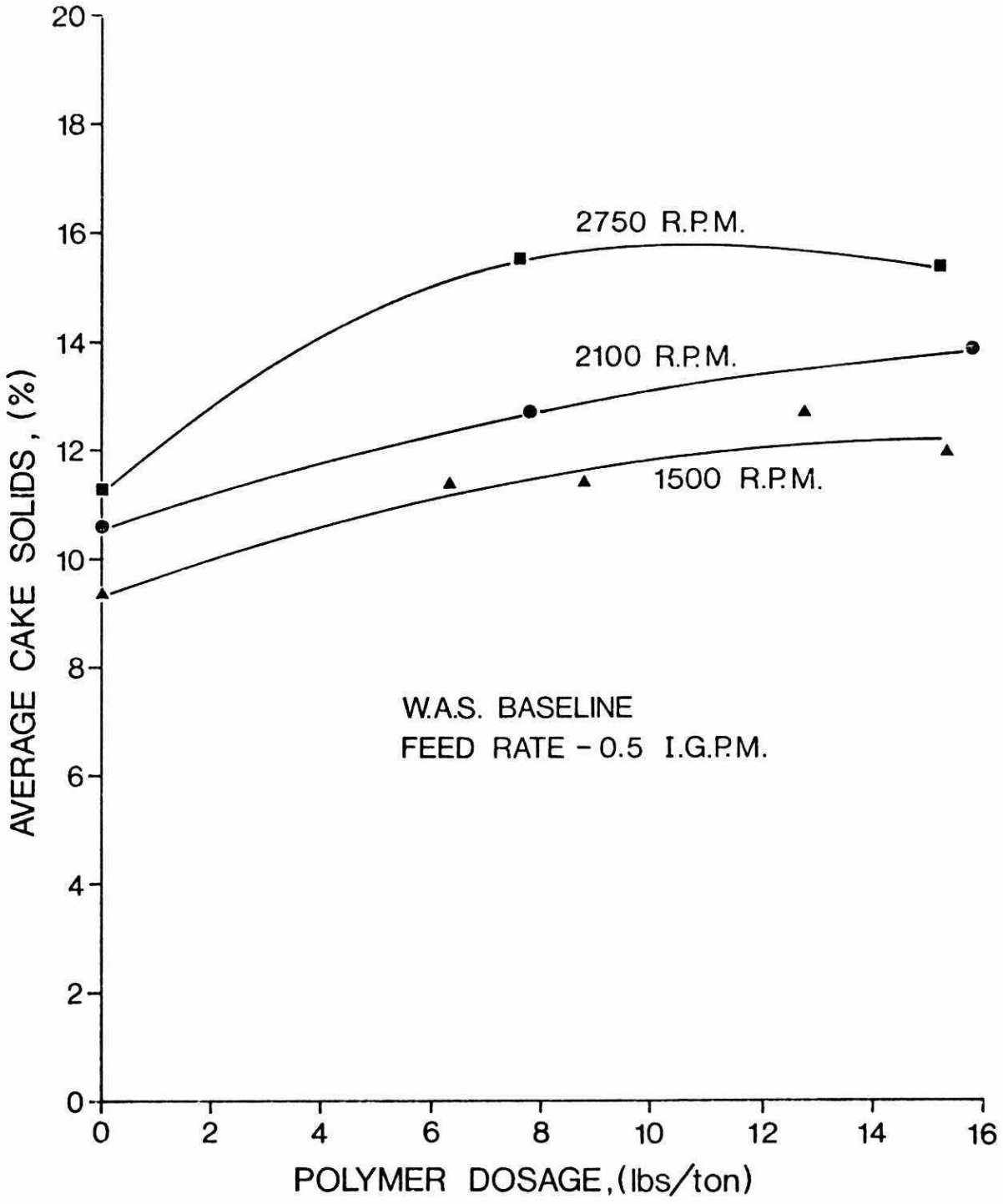

FIGURE 10. EFFECT OF POLYMER DOSAGE AND BOWL SPEED (CENTRIFUGAL FORCE) ON CAKE SOLIDS CONCENTRATION FOR THE SHARPLES/FLETCHER MARK III CENTRIFUGE.

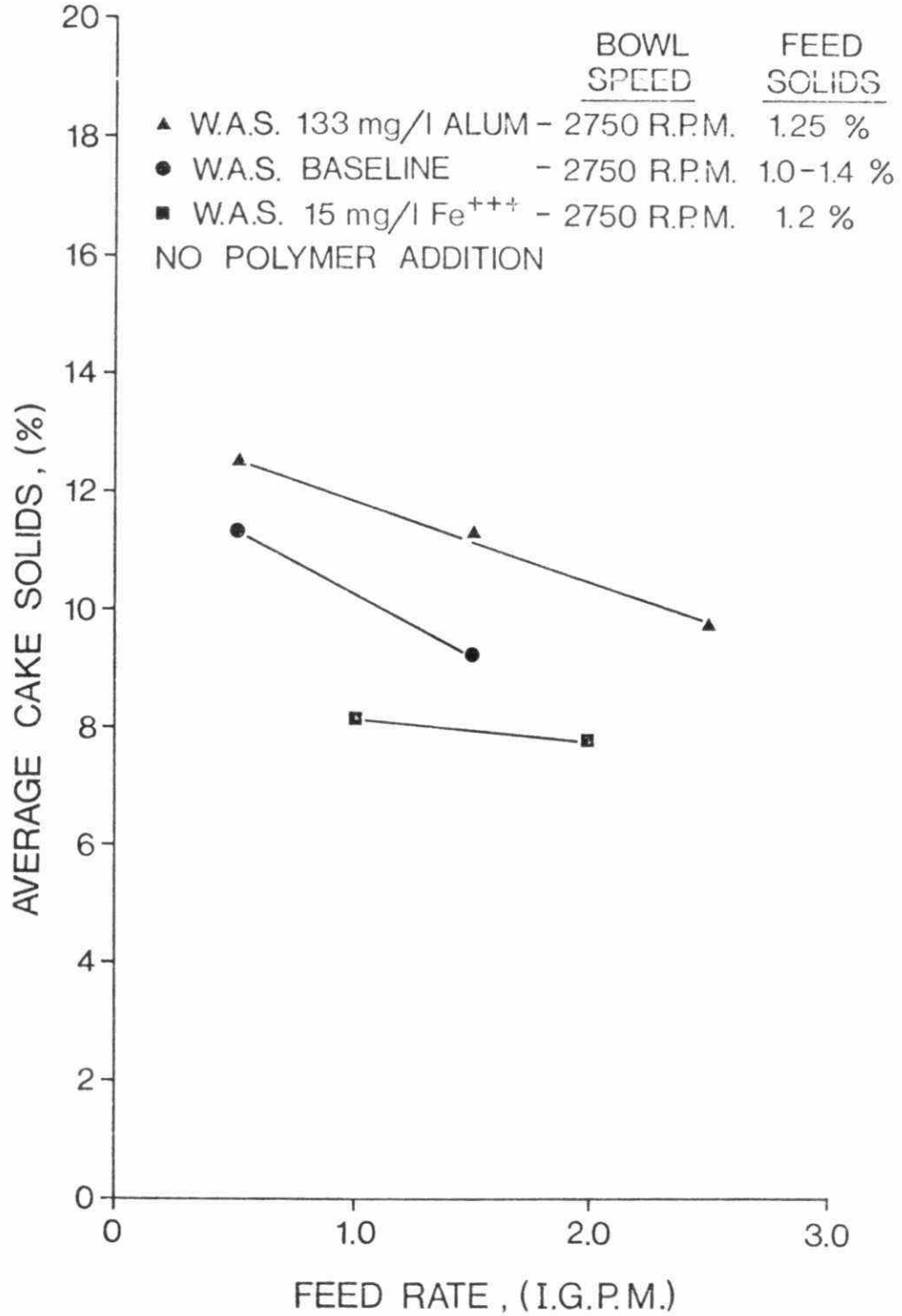

FIGURE 11. EFFECT OF FEED RATE AND TYPE OF SLUDGE ON CAKE SOLIDS CONCENTRATION FOR THE SHARPLES/FLETCHER MARK III CENTRIFUGE.

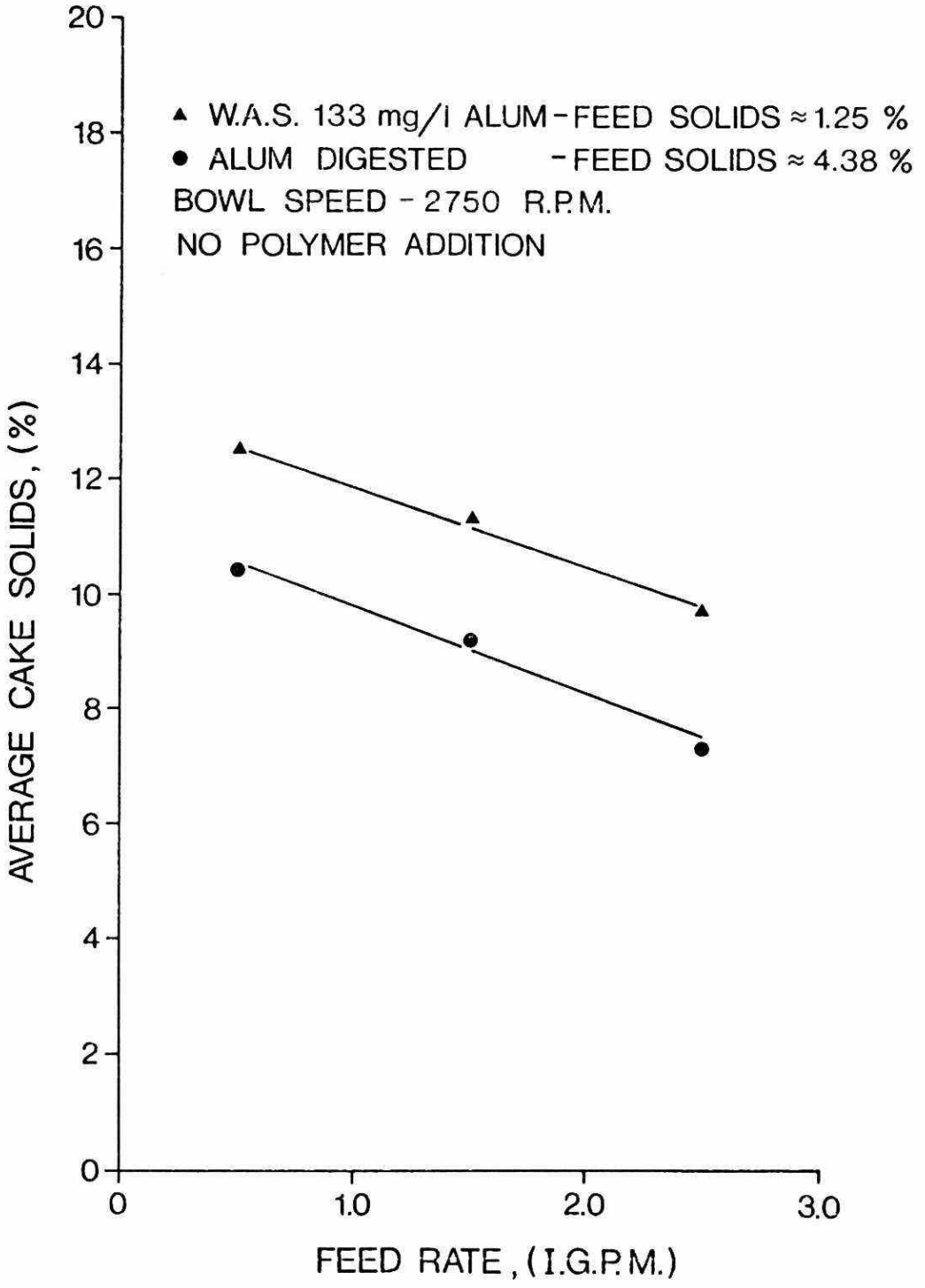

FIGURE 12. EFFECT OF FEED RATE AND FEED SOLIDS CONCENTRATION ON CAKE SOLIDS CONCENTRATION FOR THE SHARPLES/FLETCHER MARK III CENTRIFUGE.

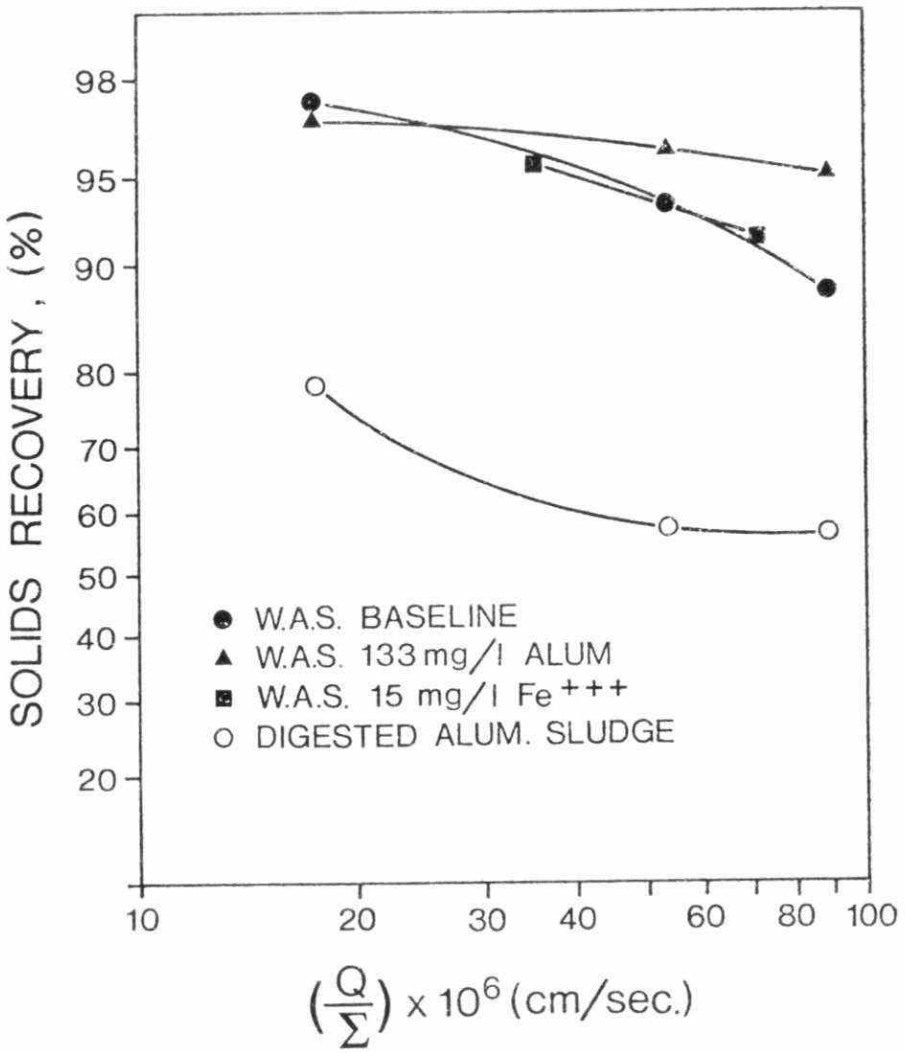

FIGURE 13. SEDIMENTATION PERFORMANCE VERSUS Q/Σ PARAMETER FOR SHARPLES/FLETCHER MARK III CENTRIFUGE.

investigated. This problem was further aggravated by changes in the feed solids concentration, making it difficult to hold two of the control variables constant while the effect of changing the third was studied. However, the units did show a definite response to a change in one of the control variables but the scatter of data points was such that general conclusions could not be drawn for all four units.

The range of operating conditons and the resulting performance for each unit is shown in Table 2. The results of the study showed that comparable performance was achieved on all four units when operated at approximately the same conditions. The maximum values for the effluent suspended solids for the two pilot-scale units (.092 and 1.39m^2) may be somewhat misleading. These maximum values represented only a fraction of the tests with most values being less than 50 mg/1. The data obtained from either of the three smallest units reasonably predicts the performance of the full-scale unit. A greater degree of caution may be required when using data from the batch tests because of the fact that solids loading in terms of Kg/m^2-hr has little meaning for this unit. Excellent recovery (99% plus) and thickening of 2 to 4 times that of the feed was accomplished on each unit with the addition of relatively low polymer dosages (less than 2.5 Kg/ton).

6 SUMMARY

Polymer dosage is the most important adjustable control variable in solid bowl centrifugation. Incorrect selection of other control variables for a particular sludge may be compensated for by increasing the polymer dosage, but in many cases operation is practically impossible without the use of polymer. Solids recoveries of 99% were possible for all sludges tested. Cake solids ranged from approximately 6-18% and were not as susceptible to changes in the control variables as solids recovery. No attempt was made to scale-up from the Sharples P-600 Super-D-Canter to the Kruger K-500 as dissimilarities in the geometry of the two machines negate use of the Sigman and Beta scaling concept. However, Sigma and Beta values were calculated and related to solids recovery. The results demonstrate that solids feed rate as well as liquid flow rate must be considered when scaling a centrifuge as suggested by Vesilind (2).

TABLE 2. A COMPARISON OF THE PERFORMANCE OF DIFFERENT SIZED AIR FLOTATION UNITS ON HAMILTON WASTE ACTIVATED SLUDGE

TYPE OF UNIT	BATCH	CONTINUOUS	CONTINUOUS	CONTINUOUS
Area m^2	.0182	.0929	1.3935	37.16
$(ft)^2$	(.196)	(1.0)	(15.0)	(400.0)
Sludge Feed Rate m^3/hr	-	.06 - .066	.546 - 1.256	39.3
(Igpm)	-	(.22-.24)	(2.0-4.6)	(144)
Recycle Ratio %	250 - 425	250 - 550	400 - 680	612
Solids Loading Kg/m^2-hr	-	14.24 - 14.63	6.05 - 15.95	13.66 - 15.61
$(lbs/ft^2$-hr)		(2.92 - 3.0)	1.24 - 3.27	(2.8 - 3.2)
Air/Solids Ratio g/g	.0123-.0254	.0123-.0258	.0126-.0482	.0237-.0272
Polymer Dosage kg/ton	1.0 - 1.5	1.0 - 1.52	.95 - 2.4	.85 - 1.75
(lbs/ton)	(2.0 - 3.0)	(2.0 - 3.04)	(1.9 - 4.8)	(1.7 - 3.5)
Effluent Suspended Solids mg/l	7 - 58	32 - 177	7 - 49	6 - 15
Float Solids %	4.9 - 6.3	4.0 - 5.2	5.3 - 8.2	6.2 - 7.4
Solids Recovery %	99.73 - 99.99	99.42 - 99.92	98.81 - 99.96	99.92 - 99.97
Hydraulic Loading m^3/m^2 hr.	-	0.65 - 0.71	0.39 - 0.90	1.05
(Igal/ft^2min)	-	(0.22 - 0.24)	(0.13 - 0.31)	(0.36)

With the basket centrifuge, recoveries in excess of 90% were possible without the use of polymer aids for all waste activated sludge investigated. However, polymer addition was necessary to produce the same degree of recovery with the digested alum sludge. Effluent quality, cake solids concentration and length of operating cycle could be increased by increasing centrifugal force and polymer addition. Increasing the feed rate changed the performance parameters in the opposite direction.

The data obtained from the bench and pilot-scale air flotation units reasonably predict the performance of the full-scale unit. Batch air flotation and 0.092m area bench dissolved air flotation results may be used to design full-scale units with reasonable precision. Excellent solids recovery (>99%) and thickening of 2 to 4 times the feed could be accomplished with low polymer dosages (≤2.5 Kg/ton). With respect to the waste activated sludge from Hamilton Sewage Treatment Plant, air flotation proved to be the superior process for clarification while centrifugation accomplished the greatest degree of thickening. No comparisons can be made as to the respective polymer dosage required because a different polymer was used for each process.

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THE USE OF PHYSICOCHEMICAL SLUDGE CHARACTERISTICS AND BENCH DEWATERING TESTS IN PREDICTING THE EFFICIENCY OF THICKENING AND DEWATERING PROCESSES

by

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1 INTRODUCTION

In August 1971 the Government of Canada and the Government of the Province of Ontario signed an agreement to ensure that the water quality of the Great Lakes is restored and protected. This "Canada-Ontario Agreement on Great Lakes Water Quality" was signed in response to recommendations of the IJC concerning pollution of the Lower Great Lakes and in anticipation of the Canada-United States Agreement on Great Lakes Water Quality. The Agreement specifies that nutrient (nitrogen, carbon and phosphorus) levels in waste treatment plant effluents should be drastically reduced, since these nutrients are considered essential elements for algal growth. Conventional treatment schemes for removing these elements will increase sludge production and may result in sludge characteristics which cause dewatering and disposal problems. As a result a provision was included in the agreement for research programs to examine these areas with a view to reducing the capital and operating costs required to achieve the specific waste quality.

The "Sludge Treatment Process Development Program" which was initiated at this time was aimed at measuring sludge production, characteristizing sludges with respect to their physical and chemical properties and correlating these properties with the efficiency of various sludge dewatering processes. Part II of the program examined control variables and scale-up techniques of the following sludge dewatering processes: vacuum filtration, centrifugation, dissolved air flotation, gravity thickening and pressure filtration. The specific objectives of the study were as follows:

(1) measurement of sludge production and properties resulting from various chemical treatments for phosphorus removal;

(2) assessment of sludge physical properties as indicators of dewatering and handling difficulty;

(3) measurement of the effects of various chemical and mechanical conditioners on characteristic properties of sludges and dewatering process control parameters;

(4) assessment of various bench-scale sludge dewatering tests;

(5) evaluation of dewatering devices at full or pilot-scale to assess the effect of control variables and sludge properties on performance;

(6) development of scale-up methodology by correlating bench, pilot and full scale dewatering test results.

This paper will address some questions of sludge production and properties resulting from various chemical treatments for phosphorus removal and methodology of scale-up for correlating bench, pilot and full scale dewatering tests. The data on sludge production and properties were obtained over the last two years from pilot plant runs at the Wastewater Technology Centre. Studies on vacuum filtration and centrifugation began in January 1974 and are continuing. Similar studies are currently underway on dissolved air flotation, plate and frame pressure filtration and gravity thickening. By the end of the program raw primary, waste activated and digested sludges from 20-25 treatment plants in Ontario will have been examined. At that time it is expected that general recommendations on sludge dewatering alternatives, scale-up methodology and costs can be made.

2 DESCRIPTION OF EQUIPMENT AVAILABLE

To meet its objectives, the Wastewater Technology Centre has developed a sophisticated analytical laboratory for measuring physico-chemical properties, fabricated a mobile bench pilot-scale sludge dewatering facility and assembled a number of mobile pilot-scale dewatering units. These facilities have been extensively described by Campbell and LeClair (1) and will not be delineated here.

3 SLUDGE SOURCES

The sludges examined in the study were obtained from the following treatment plants: City of Hamilton Sewage Treatment Plant, North Toronto Plant of the City of Toronto, Town of Tillsonburg Treatment Plant, Town of Newmarket Treatment Plant, C.F.B. Borden Treatment Plant and the physical-chemical and extended aeration pilot plants of the Wastewater Technology Centre. Summary data on the Hamilton and Tillsonburg Treatment Plants may be obtained from the literature (Campbell and LeClair (1)).

3.1 C.F.B. Borden Sewage Treatment Plant

The wastewater treatment process at C.F.B. Borden consists of screening, grit removal, primary sedimentation and chlorination before discharge to the Pine River, which subsequently discharges to the Nottawasaga River, a tributary of Georgian Bay. Sludge handling facilities consist of two-stage anaerobic digesters, drying beds and subsequent trucking to a disposal site. The plant was originally designed to treat the sewage flow from 30,000 to 40,000 base residents; however, the present population of the base is approximately 10,000 and, consequently, the plant is hydraulically underloaded. The average raw wastewater flow to the plant was 2017 m^3/day (0.64 I mgd) with a BOD_5 of 150 mg/l and a suspended solids of 130 mg/l. During the period when sludge was obtained from this plant a phosphorus removal study was in progress; 250 mg/l of calcium was being added to a rapid mix tank which had been installed ahead of the primary clarifier (2).

3.2 City of Toronto, North Toronto Treatment Plant

The North Toronto Treatment Plant is a conventional activated sludge plant with a design capacity of 23,750 m^3/day (7.5 I mgd). The raw sewage to the plant has an average BOD_5 of 164 mg/l and a suspended solids of 200 mg/l. Phosphorus removal is accomplished by the addition of 15 mg Fe/l to the aeration tank. Waste activated and raw primary sludges are reduced and stabilized by two-stage anaerobic digestion (30 days detention, solids loading 1.66 Kg/m^3/day (o.1 lb/ft^3/day)). The digested sludge is deatered by vacuum filtration (22 Kg/m^2/hr (4.5 lb/ft^2/hr)) and trucked to a land fill (3). The sludge in this study was obtained from the digesters.

3.3 Town of Newmarket Wastewater Treatment Plant

The Newmarket Wastewater Treatment Plant is a conventional

activated sludge plant with a design capacity of 9080 m^3/day (2 I mgd). The raw waste, which has a BOD_5 of 210 mg/l and a suspended solids of 380 mg/l, is primarily residential sewage with a minor contribution from local industries. Phosphorus removal is accomplished by the introduction of 200 mg/l of $Ca(OH)_2$ to a rapid mix tank located just prior to the primary clarifiers. The primary and waste activated sludges are reduced and stabilized by digestion in a two-stage anaerobic digestion system (38 days detention, solids loading 0.82 Kg/m^3/day (0.05 lb/ft^3/day)) (4).

3.4 Extended Aeration Pilot Plant - Wastewater Technology Centre

The extended aeration pilot plant at the Wastewater Technology Centre was operated at its design flow of 4.54 m^3/HR (20 I gpm) giving a detention time of 24 hours in the aeration compartment. Oxygen was supplied by a diffused air system. The clarifier detention time was 3.8 hours and had a surface loading rate of 8.48 m^3/m^2/day (250 I gal/ft^2/day). Sludge was wasted intermittently to maintain a mixed liquor suspended solids concentration of approximately 4000 to 5000 mg/l. The solids concentration of the waste sludge ranged from 0.95 to 1.4%. Incoming feed to the plant consisted of raw sewage from the City of Burlington haveing an average BOD_5 of 150 mg/l and a suspended solids concentration of 240 mg/l. Removals of 95% or better were normally achieved for both BOD_5 and suspended solids.

Sludge was obtained from this plant while it was operating without chemical addition for phosphorus removal (baseline), with the addition of 133 and 200 mg/l of $Al_2(SO_4)_3 \cdot 14\ H_2O$, and with the addition of 15 and 30 mg/l of ferric iron. The alum was added as a liquid solution to the transfer pipe between the aeration tank and the clarifier, while the ferric iron was added as a solution of ferric chloride at the head end of the aeration tank.

3.5 Physical-Chemical Pilot Plant - Wastewater Technology Centre

The physical-chemical plant operates on a constant flow rate of 4.54 m^3/hr (20 I gpm). It consists of a rapid-mix tank with a retention time of 5.5 minutes, followed by two flocculators in series, each

with a retention time of 23 minutes. Chemical coagulants such as aluminum sulphate, ferric chloride and lime are added to the rapid-mix tank. Polymer when used is added to the second clarifier. After flocculating, the wastewater flows to a clarifier with a retention time of two hours and an overflow rate of 20 $m^3/m^2/day$ (600 I $gal/ft^2/day$). Sludge is wasted periodically from the clarifier to maintain an approximate sludge blanket of about 15 inches.

During the powdered activated carbon pilot plant experiment, a contact tank with 14 minutes of retention time was placed before the rapid-mix tank to provide contact between the powder and raw sewage. A powder slurry with a five percent concentration was fed to the contact tank. During the high lime-recarbonation experiment, a recarbonation unit was added to the circuit. It consisted of a CO_2 contact tank with a retention time of 1.5 minutes, a clarifier with a retention time of 1.0 hours and an overflow rate of 40.7 $m^3/m^2/day$ (1200 I $gal/ft^2/day$) followed by a final contact tank where sulphuric acid was added to bring the pH to 7.0.

4 BENCH TESTS AND SCALE-UP METHODS

4.1 Solid Bowl Centrifuge

The machine factors which affect the performance of a centrifuge may be benerally classified as those wich are fixed in the design of a particular machine and those which can be adjusted during operation. The first group includes bowl configuration (conical, cylindrical-conical), length to diameter ratio of the bowl, bench angle and length, and scroll configuration (number of flights and pitch). The second group includes sludge pool volume, bowl rotational speed (centrifugal force), scroll differential speed, sludge feed rate, polyelectrolyte dosage, and point of polyelectrolyte addition. The relative importance of these variables is largely dependent upon the characteristics of the sludge being centrifuged.

The sludge characteristics which affect centrifugal dewatering are: (1) size, shape, density and charge of the solid particles; (2) viscosity of the sludge and sludge centrate; (3) compressibility of the solid particles; and (4) solids concentration and chemical

composition. From the theory, it is apparent that settling velocity and therefore clarifying capacity of a given centrifuge will increase with increased particle size, greater solid-liquid density difference, and the decreasing liquid viscosity. However, colloidal behaviour is responsible for the dewatering character of most sewage sludges. Although they normally represent only one-sixth of the total solids, they normally exert one-third of the conditioning flocculant demand. The conditioning process results in destabilization of the colloid and a flocculation reaction wherein individual sludge particles are united into rather loosely bound aggregates, thereby increasing their effective particle size.

The most widely used method of sizing a full-scale centrifuge has been to scale-up the results from a geometrically similar pilot-scale unit using the Sigma theory. The parameter Sigma (Σ) contains only the characteristics of the centrifuge and may be defined as:

$$\Sigma = \frac{V\omega^2}{g \ln \frac{r_2}{r_1}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where V = pool volume

ω = rotational speed

r_2 = radius of the centrifuge bowl

r_1 = radius to the inner surface of the liquid layer in the bowl

g = gravitational constant

This Sigma concept which was developed by Ambler (5), has been extensively analyzed by Vesilind (6) and Shultz (7). Vesilind (6) points out that the Sigma concept for scale-up is valid only when the centrifuge performance is limited by liquid capacity. Where solids capacity is limiting the Sigma concept breaks down, as a result Vesilind developed an alternative method of scale-up using a Beta factor. Again Beta (β) is a function of machine variables and is defined as:

$$\beta = SN\pi Dp \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where S = spacing between conveyor blades

N = the number of leads (flights)

D = bowl diameter

p = pool depth

Systems involving sewage sludges are far from ideal, as a result both the Sigma and Beta concepts have severe limitations. However, where possible, it is suggested that scale-up be conducted using both methods and the limiting one used for design purposes (6).

When data from geometrically similar machines is not available, laboratory tests may be used to predict the performance. Vesilind developed tests for estimating the cake solids and solids recovery. The cake solids test (8) is based upon measurements of samples spun in a laboratory centrifuge at the centrifugal force of the machine. It yields the solids concentration which would occur with a machine attaining 100% solids recovery. As many machines are designed to operate close to 100% recovery, the results are of value in design. The solids recovery test (9) is also based upon measurements of samples spun on a laboratory centrifuge. Data are correlated to actual centrifuge performance by simple regression analysis. The model used encompasses both sludge settling and scrolling properties. Specifically:

$$\text{Recovery} = K \frac{(C_f - C_c)^m}{C_f} p^n \quad \text{.....(3)}$$

where K, m, and n are constants determined by fitting the data

C_f = feed solids concentration

C_c = centrate solids concentration

P = results of a penetration test

4.2 Vacuum Filtration

The conventional cloth-covered vacuum filter utilizes a sectionalized drum, where the periphery of each drum section contains a raised strip upon which the edge of the filter medium rests and seals the vacuum side from the atmosphere. The seal obtained permits filter operating vacuums of 20-25 inches of vacuum. The filter cycle is normally divided into two vacuum zones. One zone is designed for cake

formation and the other for cake drying. The filter medium is an endless belt which leaves the drum and passes over a small diameter roller where the cake is discharged. The belt then passes under a wash roller where the medium may be washed.

The factors which affect the filtration of sludges can be categorized into two main classes: the characteristics of the sludge, and the characteristics of the sludge dewatering system. The characteristics of the sludge include:

(a) the shape and characteristics of the solid particles in the sludge to be dewatered;

(b) the chemical composition of the sludge, namely a sludge primarily organic in nature or primarily inorganic;

(c) the compressibility of the solids in the sludge;

(d) the suspended solids content of the sludge; and

(e) the viscosity of the filtrate and viscosity and specific resistance of the sludge.

The first three characteristics are fixed, and very little can be done to change them. The suspended solids content can be altered by thickening the sludge. Generally it has been observed that sludge filtration rates increase with increasing feed solids concentration. The viscosity of the filtrate as well as the viscosity and specific resistance of the sludge can be altered by properly conditioning the sludge. Various materials, organic and inorganic chemicals, and physical processes have been applied to the sludge to reduce the specific resistance and thereby increase the obtainable filter loadings.

The machine characteristics which must be considered in the sizing, selection and operation of a vacuum filter include:

(a) the type of filter medium used;

(b) the operating pressure;

(c) the cycle time; and

(d) fraction of the cycle used for cake formation (submergence).

To obtain optimum filtration results the filter medium must be fitted to the particular situation and sludge to be dewatered. Digested and waste activated sludges which contain a relatively high proportion of fine particles can normally best be dewatered on tight weave cloths. Monofilament polyethylene and polypropylene have found good application on these sludges. Undigested primary sludges, at the other extreme, have been handled most successfully with a relatively open nylon media. Maximum sludge filtration rates are obtained when the pressure drop through the cake and the fraction of the cycle time used for cake formation are maximized and the filter cycle time is minimized.

The most widely used method for sizing a full scale vacuum filter has been the leaf test (10). Leaf tests can be made to simulate full scale filter operating conditions and results obtained from the tests predict with a high degree of precision full scale filtration rates and cake moistures at various operating conditions. Another method for the prediction of vacuum filter yields was developed by Gale (11). The buchner funnel test was used. Subject to certain limitations, it was shown that over a twentyfold range of yiedls, the measured yields were within 30 percent of those predicted.

5 RESULTS

5.1 Sludge Production and Characteristics

Phosphorus removal or upgrading can be accomplished by adding chemicals (alums, lime, ferric chloride or polymers) to enhance the removal of suspended solids, BOD_5, and phosphorus in the primary or secondary clarifiers. The increased amount of sludge produced may be approximated by referring to pilot plant and field data or by a calculational approach. The characteristics of the sludge may have an impact on the method selected for dewatering, although physical-chemical processes produce sludges whose dewatering properties are not yet fully understood. The addition of chemicals for phosphorus removal was studied at the Wastewater Technology Centre to assess sludge production and characteristics. A primary and extended aeration pilot plant were examined under various chemical treatments.

The sludge production and characteristics data for the various chemical treatments of raw sewage are presented in Tables 1 and 2. It is apparent that chemical additions change the sludge characteristics (Table 1). The percentage of organics increased, dry solids density increased, volatile solids decreased and the coefficient of compressibility increased with chemical type and dose. Underflow sludge concentrations were generally lower than baseline (2 fold increase) when alum or ferric chloride were added; lime treatment increased the underflow concentration 3 fold.

The dewatering requirement also decreased slightly with chemical treatment as evidenced by the reduced resistivity and capillary suction time (CST) measurements. The capillary suction time does not give a direct measure of specific resistance to filtration, however, it may be calibrated against specific resistance for one particular sludge. It has been included here because it permits the measurement of filterability rapidly and with a minimum of manipulation. Thus it should normally be used in testing chemical conditioners.

In assessing the size of the dewatering unit required (the vacuum filter for example) for various chemical treatments, both sludge production rate and dewatering characteristics must be considered. Table 2 provides a comparison for various chemical treatments. The filter area required was calculated after the method of Gale (11). This method uses buchner funnel data. The data. The equation for the yield, when the resistance to the filter medium is zero, is

$$Y = \frac{2P \cdot C_1 \cdot F_f}{\eta \quad r_p \quad \Theta_R} \; \tfrac{1}{2} F_c \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where Y = yield of filter in mass of dry suspended solids produced in unit time per unit of total area of filter medium

p = pressure difference across filter cake during cake formation

η = viscosity of filtrate

TABLE 1. PRIMARY SLUDGE CHARACTERISITICS

PARAMETERS \ SLUDGE	$FeSO_4$ 15 mgFe/1	LIME PH 11.2	ALUM 200 mg/1	$FeCl_3$ 30 mgFe/1	Baseline
CONCENTRATION g/1	35.5	96.1	20.2	15.8	34.1
DENSITY SUSPENSION g/cm^3	1.0117	1.0548	1.0057	1.0049	1.0079
DENSITY DRY SOLIDS g/cm^3	1.68	2.09	1.73	1.69	1.39
RESISTIVITY $sec^2/g \times 10^{-7}$	406	7.36	279	359	453
CAPILLARY SUCTION TIME sec	70.6	26.4	29.7	34.2	81.7
VOLATILE SOLIDS %	-	18	50	52	71
COEFFICIENT OF COMPRES-SIBILITY	-	0.88	0.84	0.73	0.63
WT. FRACTION CHEMICAL SLUDGE	-	0.90	0.32	0.32	-

TABLE 2. SLUDGE PRODUCTION AND FILTER AREA REQUIREMENTS FOR VARIOUS CHEMICAL TREATMENTS (PRIMARY SLUDGE)

CHEMICAL TREATMENT FOR P-REMOVAL	SLUDGE SOLIDS g/l	SLUDGE [1] PRODUCTION Kg/m^3	RESISTIVITY $\times 10^{-7}$ sec^2/g	CAKE SOLIDS %	RELATIVE FILTER AREA
Baseline	34.1	0.092	453	32.5	1.0
Lime pH 9.5	118.7	0.394	43	32.0	0.54
Lime pH 11.2	96.1	0.547	7.4	32.0	0.37
500 mg/l $Ca(OH)_2$	79.4	0.721	7.7	32.1	0.49
200 mg/l alum	20.2	0.254	280	24.0	2.73
100 mg/l PAC and 200 mg/l alum	35.8	0.372	98	21.8	1.71
30 mgFe/l (ferric chloride)	15.8	0.162	360	28.3	2.33

[1] - Weight per unit volume of raw sewage

C_1 = mass of dry suspended solids per unit volume of liquid in sludge

r_p = apparent specific resistance of cake measured at p

F_f = fraction of total filter area used for cake formation

Θ_R = time for one revolution of the filter

F_c = cake correction factor, the ratio of the mass of liquid in unit mass of sludge, to the filtrate obtained when unit mass of sludge is filtered

The equation was shown previously (12) to give predictions within 30 percent of measured yields. The 3 x 1 vacuum filter provided yields of 13.6 $kg/m^2/hr$ compared to a prediction of 10 $kg/m^2/hr$ for raw primary sludge (500 mg $Ca(OH)_2/l$) in this work.

Sludge characteristics and production data for various chemical additions to the extended aeration plant are presented in Tables 3 and 4. The addition of alum had little effect on the settling characteristics, whereas ferric chloride addition reduced settling rates and underflow solids concentration two-fold. Clarifier capacity may have to be increased with ferric chloride treatment. Chemical treatment also affected the sludge dewatering characteristics, with alum providing much greater effects than ferric chloride as is indicated by the measures of dewaterability (specific resistance, ultimate settled concentration, compressibility and yield stress).

Dispersed systems (suspensions) are, in general, non-newtonian fluids, in which the suspended particles interfere with the free flow of the dispersion medium to a degree that is dependent on the rate of shear. Non-newtonian fluids exhibit several types of flow, including pseudoplastic, dilant and thixotropic. Sludges exhibit plastic flow and may be described by the Bingham Plastic Model. That is, they possess yield strengths and have shearing stresses wich are directly proportional to the shear rates once the yield stresses have been exceeded. Sludges

TABLE 3. EXTENDED AERATION WASTE ACTIVATED SLUDGE CHARACTERISTICS

SLUDGE / PARAMETER	ALUM 133 mg/1	ALUM 200 mg/1	BASELINE	FERRIC[2] IRON 15 mg/1	FERRIC[2] IRON 30 mg/1
Sludge Volume Index ml/g	46	48	60	96	92
30 Minute Settling ml/1000 ml	262	286	339	386	393
Settling Velocity cm/min	4.07	3.07	3.42	2.04	2.09
Concentration g/l	17.7	17.2	19.9	11.2	12.6
Volatile Solids %	42	48	52	59	60
Density Suspension g/cm^3	1.0073	1.0061	1.0063	1.0032	1.0022
Density Dry Solids g/cm^3	1.76	1.88	1.59	1.59	1.56
Capillary Suction Time sec	7.3	6.7	9.0	9.6	10.9
Resistivity $sec^2/g \times 10^{-7}$	44	21	157	197	166
Compressibility Coefficient	0.96	0.88	0.79	0.90	0.76
Ultimate Settled Concentration [1] g/l	41.2	38.9	29.9	30.5	29.6
Yield Point[1] $dynes/cm^2$	33	-	126	65	63

[1] - after 24 hours settling

[2] - from ferric chloride

TABLE 4. EXTENDED AERATION WASTE ACTIVATED SLUDGE PRODUCTION

PARAMETER \ SLUDGE	ALUM 133 mg/1	ALUM 200 mg/1	BASELINE	FERRIC[1] IRON 15 mg/1	FERRIC[1] IRON 30 mg/1
Concentration g/1	17.7	17.2	19.9	11.2	12.6
Volatile Solids %	42	48	52	-	60
Volume Wasted[2] m^3/m^3	0.0147	0.0163	0.0066	0.0156	0.0146
Weight Wasted[2] kg/m^3	0.26	0.28	0.13	0.18	0.16
Ratio Chem-Biol. to Baseline	1.97	2.13	-	1.32	1.24

[1] - from ferric chloride

[2] - volume or weight of sludge per unit volume raw sewage

are also thixotropic, that is, their flow resistance resulting from the application of stress is time dependent. Rheological properties are best expressed by rheograms - curves in which the rate of shear is plotted against shear stress. The Rheological properties of Hamilton waste activated sludge are presented in Figures 1 and 2. Figure 1 shows the effect of solids concentration on the rheological properties. Yield stress increases with increasing concentration. In Figure 2, the effect of polymer addition to the waste activated sludge is presented. Yield stress are increased markedly. Rheological properties correlate well with the other measures of dewaterability (Table 2) and they should be very useful parameters in characterizing sludges.

The effect of chemical treatment on excess sludge production in the extended aeration plant is presented in Table 4. Both waste activated sludge volume and solids production increased with chemical addition. With alum treatment the sludge volume and solids production increased two-fold, whereas with ferric chloride treatment the sludge volume doubled and the solids production increased by 30 percent.

5.2 Centrifugation

Sludge characteristics affect centrifugal dewatering performance. Correlation of these properties with centrifuge performance has been examined in general terms. Laboratory tests have also been suggested in the literature which can predict performance. These tests have been examined for a number of digested sludges and the waste activated sludge from the Hamilton Plant.

The chemical characteristics of the digested sludges are presented in Table 5. The sludges are similar, except for the amount of the chemical which was added for phosphorus removal. Representative effects of polymer addition for conditioning are demonstrated in Table 6. Cake solids, percent not penetrated and yield stress all increase with increasing polymer dose. Vesilind (8, 9) observed similar results for cake solids and percent not penetrated. Particle size distributions for the sludges are presented in Figure 3 and Figures 4, 5, 6 show rheograms at various polymer doses. Centrifuge performance is presented in Tables 7 and 8.

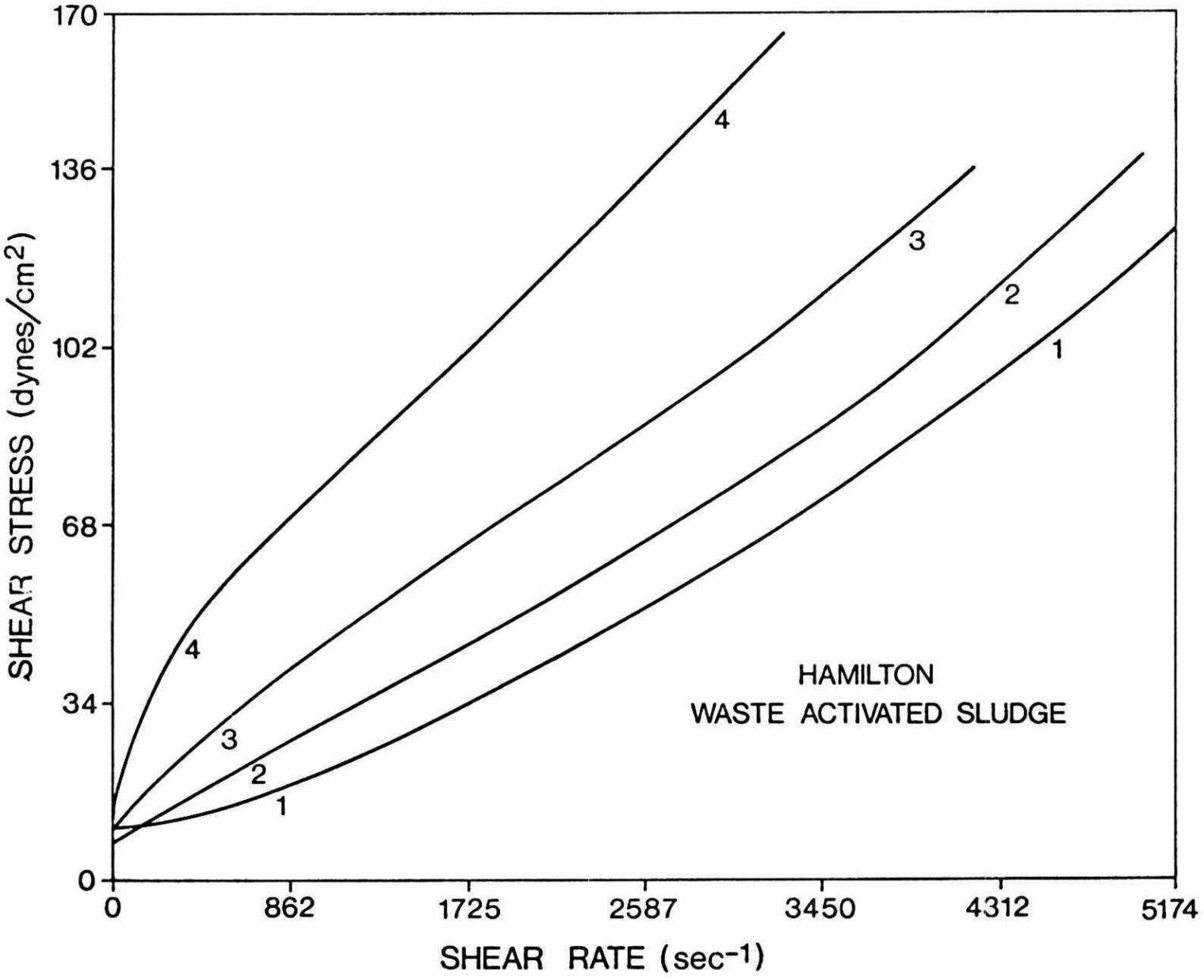

FIGURE 1. RHEOGRAMS - HAMILTON WASTE ACTIVATED SLUDGE AT VARIOUS SOLIDS CONCENTRATIONS 1 - 1 WT% 2 - 2 WT% 3 - 3 WT% 4 - 4 WT%

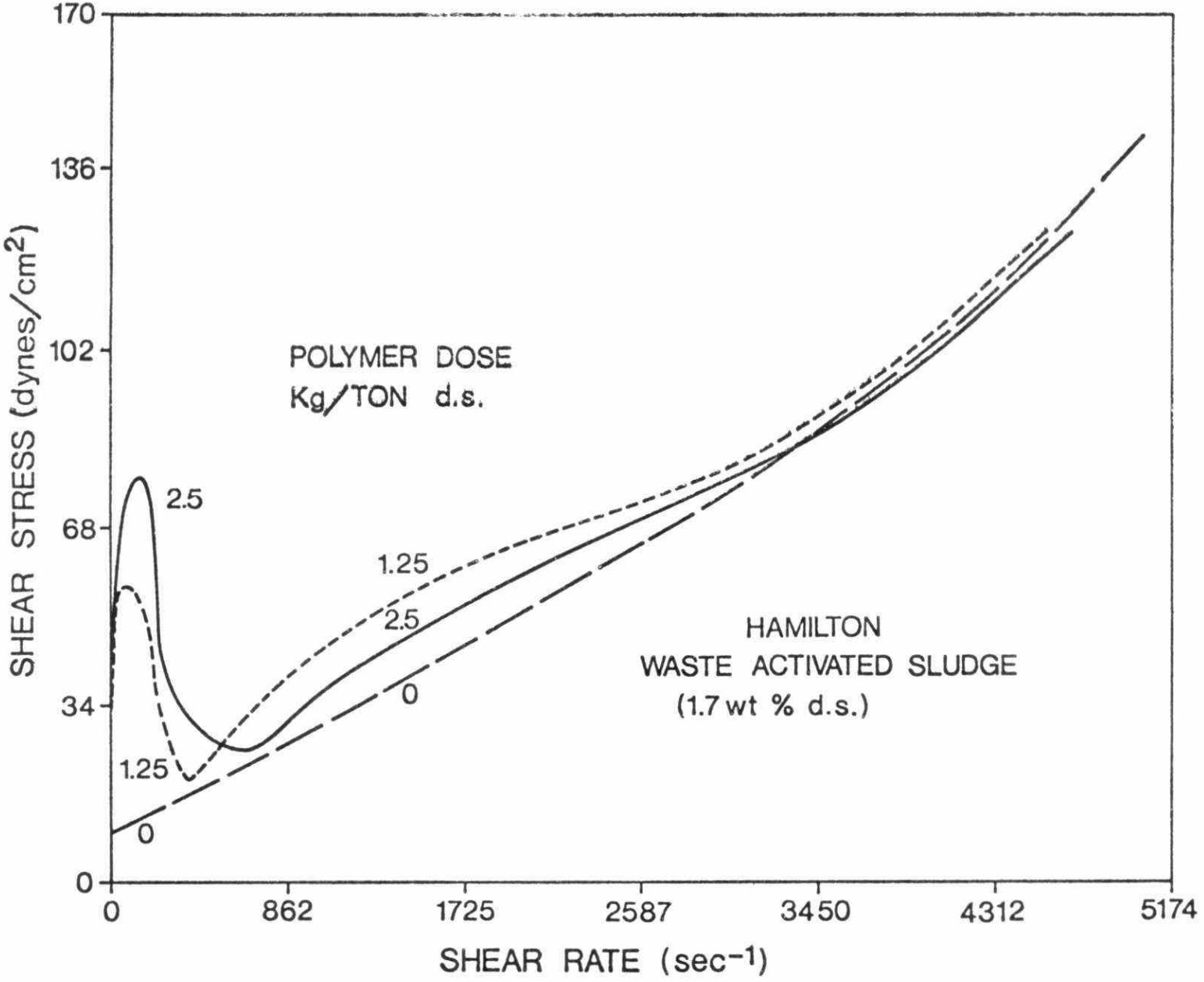

FIGURE 2. RHEOGRAMS - HAMILTON WASTE ACTIVATED SLUDGE

TABLE 5. CHEMICAL CHARACTERISTICS OF DIGESTED SLUDGES

PARAMETER / SLUDGE		TILLSONBURG ALUM	NORTH TORONTO IRON	NEWMARKET LIME
Total Solids	%	4.17	6.56	9.69
TKN	mg/l	2070	1190	3610
P	mg/l	1790	440	1530
TOTAL CARBON	%	23.6	-	26.6
Mg	mg/l	420	2440	994
Ca	%	0.8	12.4	0.6
Fe	mg/l	540	900	6000
Al	mg/l	10960	2060	2140

TABLE 6. EFFECT OF POLYMER DOSE ON BENCH TESTS

SLUDGE	POLYMER DOSE Kg/ton d.s.[1]	% NOT PENETRATED	CAKE SOLIDS %d.s.	YIELD STRESS dynes/cm^2
North Toronto	0	6.4	11.2	46.8
	1	-	-	50.4
	2	12.6	15.9	72.0
	3	17.7	16.4	162.0
	4	33.3	18.9	189.0
	5	52.1	21.9	202.0
Tillsonburg (June '74	0	No Interface	4.4	25.6
	2.5	29.2	8.3	-
	5.0	38.6	8.5	-
	7.5	76.3	10.1	79.2
	10.0	85.2	12.9	-

[1] - weight per metric ton dry solids

When the results are considered in total, generalizations are evident. Good agreement exists between the cake solids predicted by bench test (Table 6) and that obtained with the centrifuge (Table 7). For high recoveries, bench tests can be used to predict cake solids. The percent not penetrated and yield stress values could not be correlated to centrifuge performance, however, they did provide relative measurements of the performance. These tests sould be used to evaluate alternative polymer conditioners. Good agreement is demonstrated between polymer addition rheograms and centrifuge performance. The polymer dose required to provide the peak in the rheogram curve (North Toronto, 3-4 Kg/ton; Newmarket, 1-2 Kg/ton; Tillsonburg (March), 4-6 Kg/ton and Tillsonburg (June), 7.7-8.5 Kg/ton) agrees well with the optimum polymer dosage (Tables 7 and 8). The effect of particles size on performance is clearly demonstrated when Figure 3 and Table 8 are compared. Solids recovery and cake solids between March and June were reduced from 99 to 75% and from 14 to 10%, respectively at the same polymer dose when the particles changed from an average diameter of 40 microns to 10 microns.

Results similar to digested sludges were also obtained with waste activated sludges. Figure 2 and Table 9 present data obtained with Hamilton waste activated sludge. Bench tests and rheograms suggest an optimum polymer dose of approximately 1 Kg/ton for which cake solids concentration is approximately 10-11%. Actual results are 10% for cake solids and about 1.5 Kg/ton polymer dose.

5.3 Vacuum Filtration

The proper design of vacuum filtration facilities requires a knowledge of the filtration characteristics of the sludge. Relative measures of filterability can be obtained by buchner funnel or capillary suction time tests. As a result, they are normally used to establish optimum chemical dosages. Design, however, requires a solids loading correlation. Thus, filters have normally been designed on the basis of leaf tests, as this test can be made to simulate full scale operating conditions. Recently Gale (11) developed a correlation based on buchner funnel

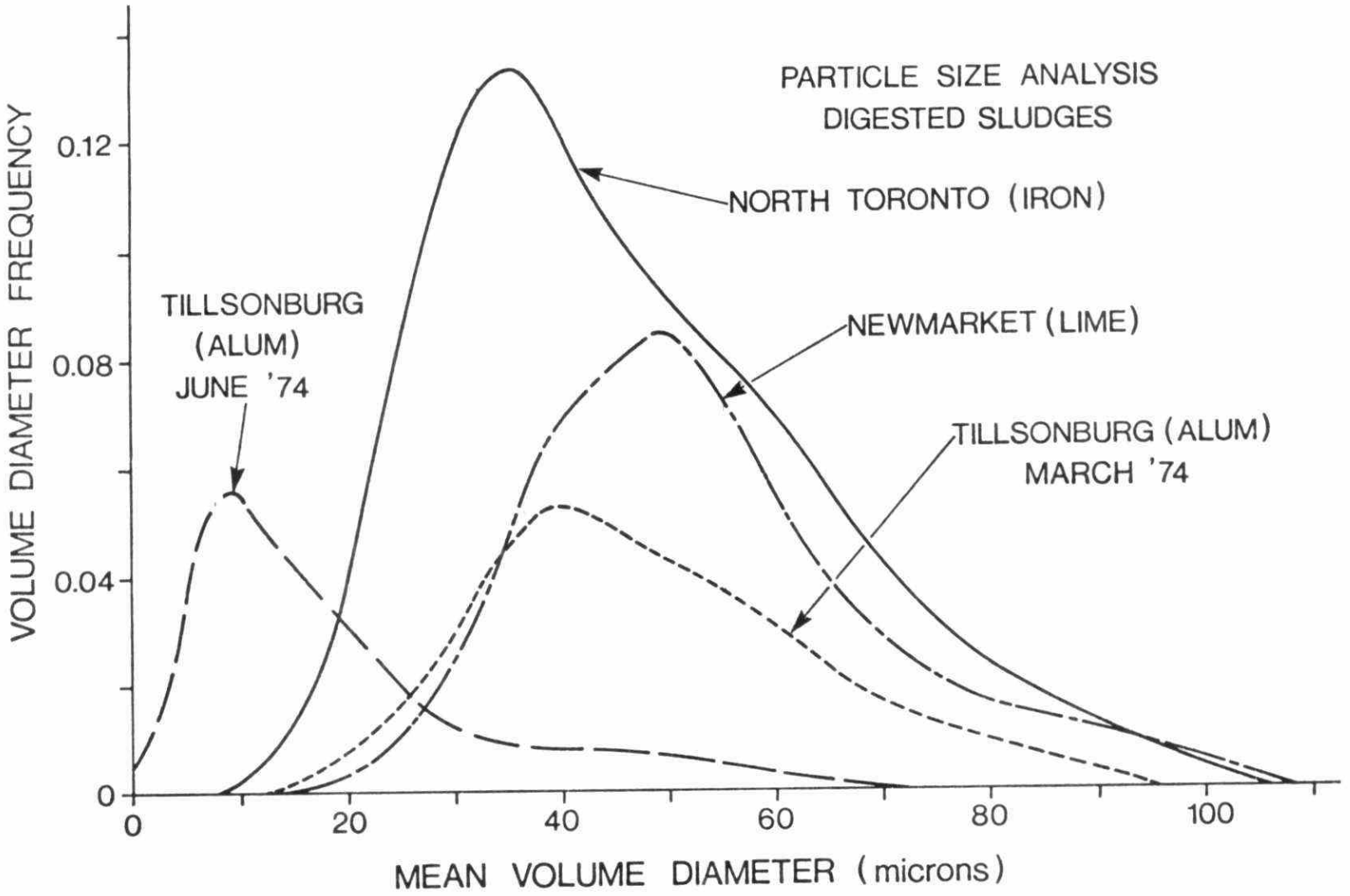

FIGURE 3. PARTICLE SIZE DISTRIBUTIONS FOR VARIOUS DIGESTED SLUDGES

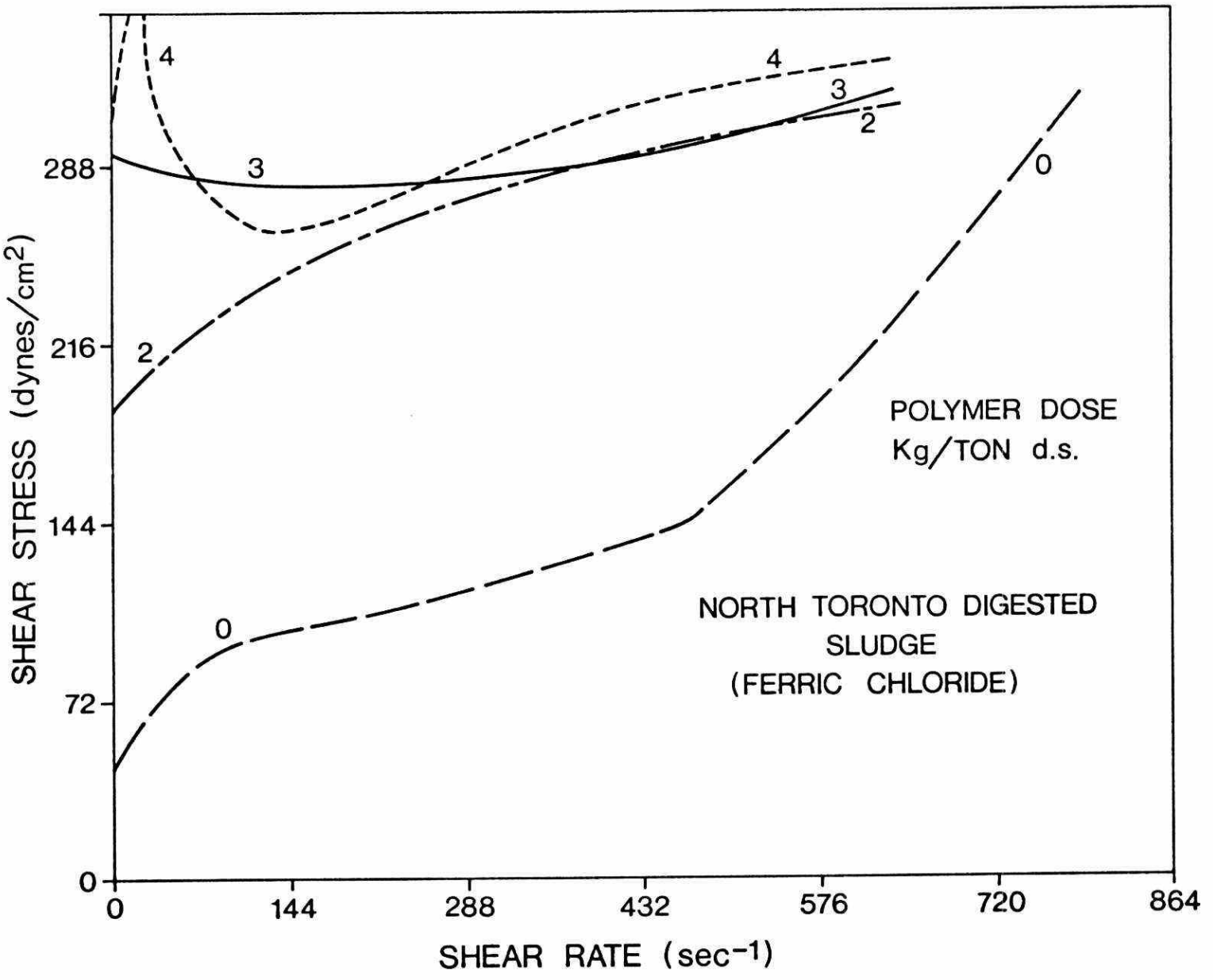

FIGURE 4. RHEOGRAMS - NORTH TORONTO DIGESTED SLUDGE

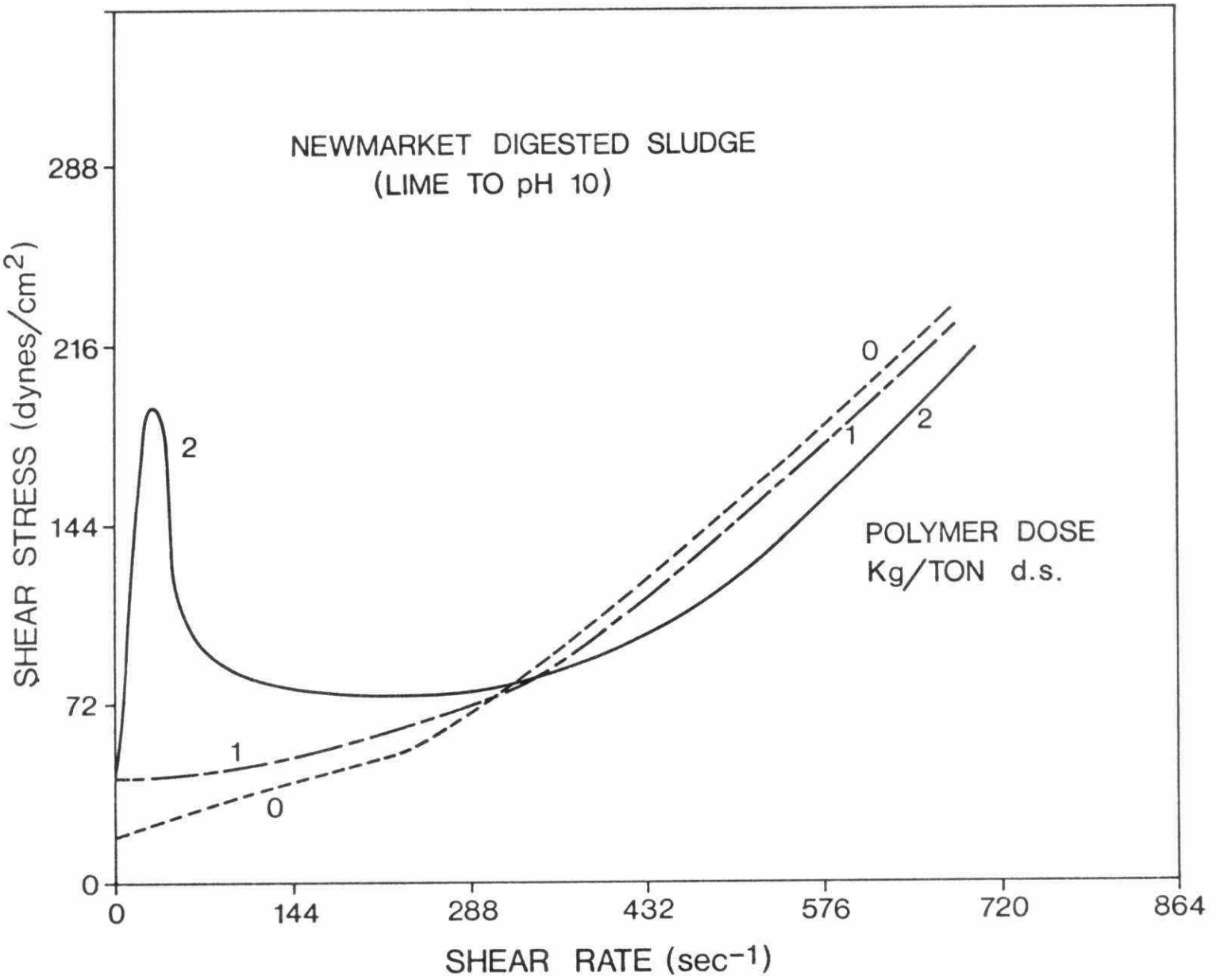

FIGURE 5. RHEOGRAMS - NEWMARKET DIGESTED SLUDGE

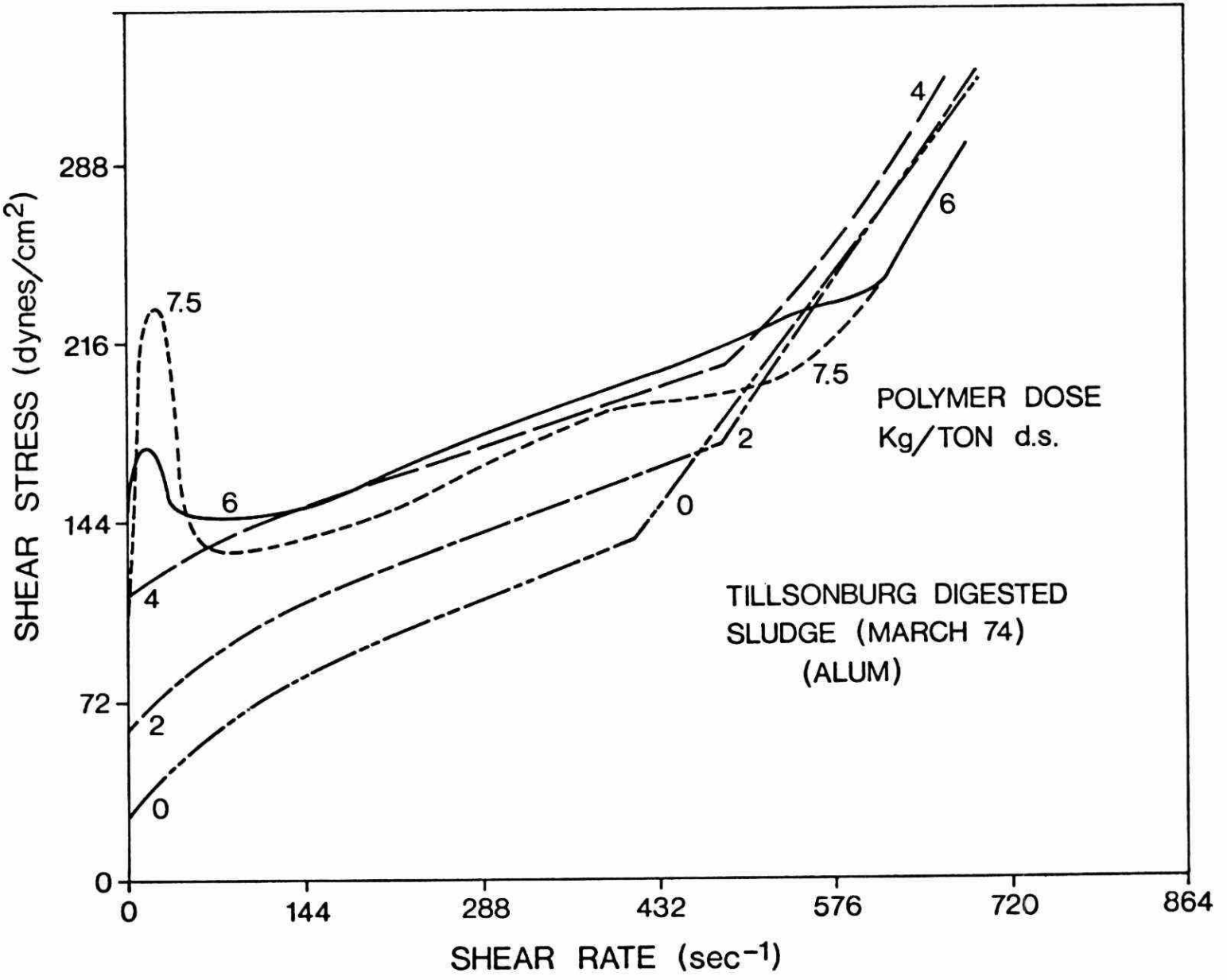

FIGURE 6. RHEOGRAMS - TILLSONBURG DIGESTED SLUDGE (MARCH 1974)

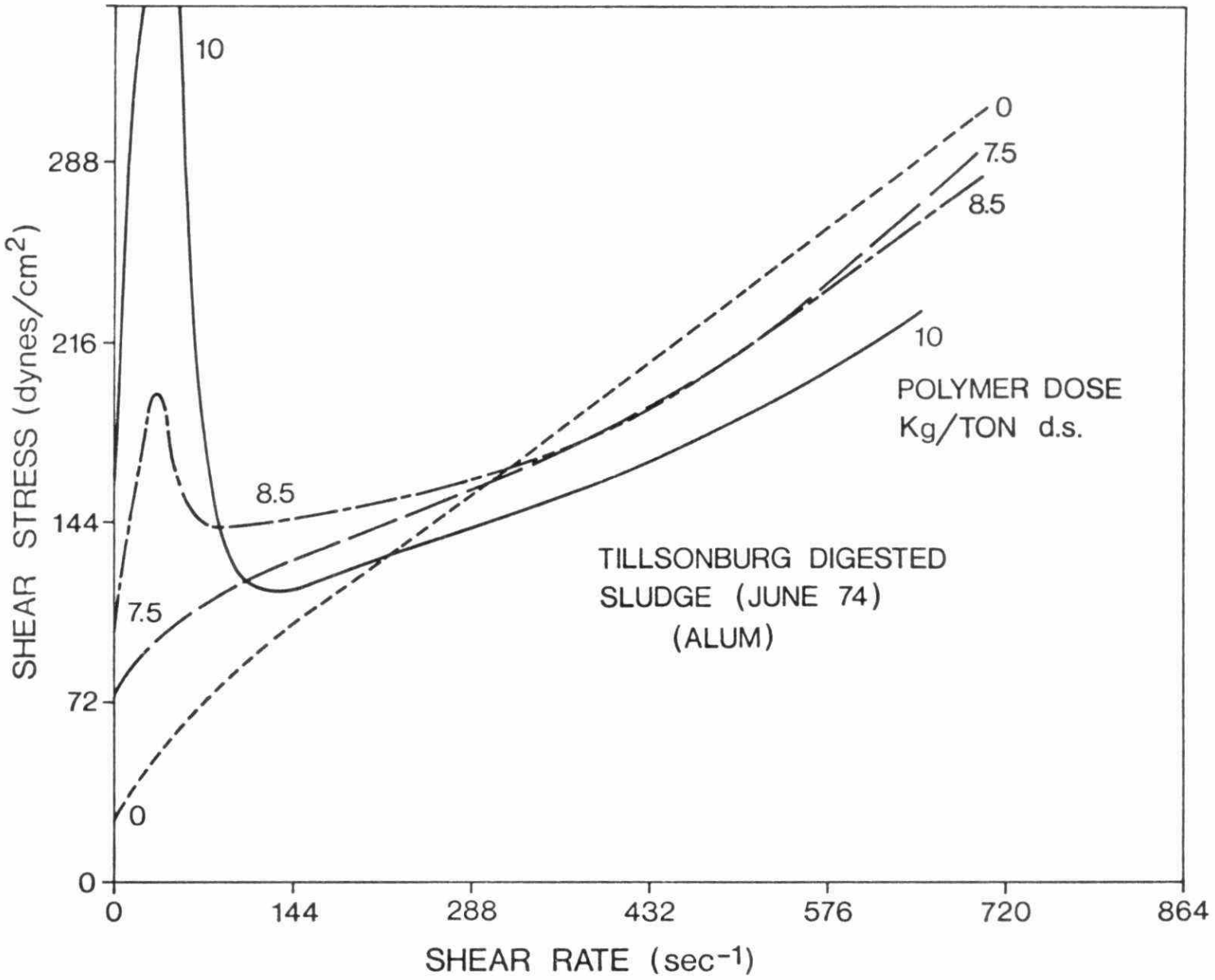

FIGURE 7. RHEOGRAMS - TILLSONBURG DIGESTED SLUDGE (JUNE 1974)

TABLE 7. CENTRIFUGATION OF DIGESTED SLUDGES P-600 CENTRIFUGE

SLUDGE / PARAMETER	TILLSONBURG (ALUM)		NEWMARKET (LIME)			NORTH TORONTO (FERRIC CHLORIDE)		
Capacity m^3/hr	.27	.27	.27	.27	.27	.27	.27	.27
Feed d.s. kg/hr	11.4	11.4	26.4	26.4	26.4	17.9	17.9	17.9
Bowl Speed rpm	5000	5000	5000	5000	5000	5000	5000	5000
Speed Diff. rpm	35	35	35	35	35	35	35	35
Pond Depth cm	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Centrifugal Force xG	2130	2130	2130	2.30	2130	2.30	2.30	2130
Polymer kg/ton d.s.[1]	4.8	6.7	0.4	0.8	1.2	4.4	5.5	6.5
Sludge Feed % d.s.	4.17	4.17	9.69	9.69	9.69	6.56	6.56	6.56
Sludge Dewatered % d.s.	12.96	14.25	44.6	39.5	37.7	24.0	17.3	18.7
Sludge Centrate % d.s.	0.05	0.06	1.88	0.03	0.02	0.11	0.16	0.03
% Recovery Solids	99	99	84	99	99	99	98	99

[1] - d.s. dry solids

TABLE 8. CENTRIFUGATION OF DIGESTED ALUM SLUDGE (TILLSONBURG)

PARAMETER / SLUDGE		MARCH 1974		JUNE 1974			
Capacity	m^3/hr	0.27	0.27	0.40	0.40	0.40	0.13
Feed d.s[1]	Kg/hr	11.4	11.4	18.3	18.3	18.3	6.1
Bowl speed	rpm	5000	5000	5000	5000	5000	5000
Speed Diff.	rpm	35	35	30.5	30.5	30.5	30.5
Pond Depth	cm	0.8	0.8	1.6	1.6	1.6	1.6
Centrifugal Force	x G	2130	2130	2130	2130	2130	2130
Polymer	Kg/ton d.s.	4.8	6.7	5.8	7	8.3	7
Sludge Feed	% d.s.	4.2	4.2	4.5	4.5	4.5	4.5
Sludge Dewatered	% d.s.	13.0	14.3	9.2	10.0	8.7	9.5
Sludge Centrate	% d.s.	0.05	0.06	2.2	1.7	1.8	1.6
% Recovery Solids		99	99	67	74	75	79

results. Full-scale units may also be scaled by using results from geometrically similar pilot or laboratory units. These various tests were investigated using raw primary sludge from Camp Borden and the Komline Sanderson minifilter and Eimco 3 x 1 filter. Results obtained are presented in Tables 10 and 11 and Figures 8 and 9. The minifilter provided yields which were approximately 50% higher than the yields obtained on the 3 x 1 filter at all cycle times and polymer dosages (Figure 8 and Tables 10 and 11). The Gale formula provided yield values which were much closer to the 3 x 1 filter than the minifilter (Figure 9). Leaf test results were midway between the two filters (Figure 9). Bench tests thus appear to provide design data which is as good as that which can be obtained from pilot plants.

6 SUMMARY

The addition of chemicals for phosphorus removal to the primary or extended aeration processe altered the sludge characteristics and production. In most cases sludge volumes and total solids production were increased. The chemical additions also had a detrimental effect on dewatering characteristics. Thus, in most cases, sludge handling facilities will have to be increased over those required before the introduction of chemical treatment. The noteable exception is lime treatment. Although sludge solids increased markedly, the dewatering characteristics improved to such an extent that the size of the sludge handling facilities could be reduced.

Sludge characteristics affect centrifugal and vacuum filtration dewatering performance. Sludge characteristics, such as specific resistance to filtration, capillary suction time and rheology provide relative measures of dewaterability. Thus, they may be used to evaluate alternative chemical conditioners, however, in themselves, they will not provide equipment sizing. With vacuum filtration, leaf tests and the Gale formula provide sizing information equal to that of pilot units. On a cost basis, bench tests are preferred. Although cake solids may be predicted with reasonable precision, procedures for sizing centrifuges based on bench tests require a great amount of development before they will be useful.

TABLE 9. HAMILTON S.T.P. WASTE ACTIVATED SLUDGE

TABLE (A). BENCH TESTS

POLYMER DOSE Kg/Ton d.s.	% NOT PENETRATED	CAKE SOLIDS %	YIELD STRESS dynes/cm^2	CST SEC
0	16.3	17.0	5.1	58.7
0.25	15.1	11.3	-	-
0.75	17.2	10.9	-	-
1.25	24.0	9.9	9.1	11.7
2.50	38.0	11.0	8.5	11.5

TABLE (B). PERFORMANCE P-600 SOLID BOWL CENTRIFUGE

Capacity m^3/hr	0.68	0.68	0.68	0.68
Feed d.s. Kg/hr	12.6	12.6	12.6	12.6
Bowl Speed rpm	4000	4000	4000	4000
Speed Diff. rpm	20	20	20	20
Pond Depth cm	1.6	1.6	1.6	1.6
Centrifugal Force xG	1360	1360	1360	1360
Polymer Dose Kg/ton d.s.	0.62	1.25	2.50	3.75
Sludge Feed %d.s.	1.93	1.93	1.93	1.93
Sludge Dewatered	8.7	9.6	10.4	10.1
Sludge Centrate % d.s.	0.29	0.05	0.02	0.02
Recovery Solids %	88	98	99	99

TABLE 10. FILTRATION RATE - 250 mg/1
PRIMARY LIME SLUDGE (CAMP BORDEN STP)[1]

POLYMER DOSE Kg/Ton	CYCLE TIME MIN	FORM Θf %	DRY Θd %	FEED SOLIDS %	CAKE SOLIDS %	CENTRATE SOLIDS %	YIELD Kg/m^2/hr
0	5.0	32	22	16.8	46.5	0.43	9.59
0	5.0	32	22	11.4	45.5	2.1	5.72
0.25	5.0	32	22	10.9	41.9	1.7	8.88
0.25	3.3	32	22	10.9	40.8	2.4	8.88
0.56	5.0	32	22	9.8	38.9	0.55	13.2
0.56	3.3	32	22	9.8	40.4	0.83	24.8
0.56	1.65	32	22	9.9	39.2	1.3	32.6
0.84	5.0	32	22	10.1	36.4	0.26	21.1
0.84	3.3	32	22	10.1	33.3	0.11	31.4
0.84	1.65	32	22	10.1	30.9	0.12	40.2
0.84	5.0	22	22	9.7	40.0	0.36	13.5
0.84	3.3	22	22	9.7	37.5	0.34	18.3
0.84	1.65	22	22	9.7	34.4	0.34	24.8

[1] Eimco 3 x 1 vacuum filter, vacuum 67.8 N/m^2(20 in. Hg), poly propylene filter media.

TABLE 11. FILTRATION RATE - 250 mg/l
PRIMARY LIME SLUDGE (CAMP BORDEN STP)[1]

POLYMER DOSE kg/Ton	CYCLE TIME min	FORM θf %	DRY θd %	FEED SOLIDS %	CAKE SOLIDS %	FILTRATE SOLIDS %	YIELD kg/m^2/hr
0.85	5	32	22	11.1	43.8	0.25	35.1
0.85	3.3	32	22	11.0	43.7	0.31	35.1
0.85	1.65	32	22	11.1	42.5	0.36	66.4
1.25	5	32	22	10.9	38.5	0.20	52.7
1.25	3.3	32	22	11.1	42.5	0.36	72.2
1.25	1.65	32	22	11.0	44.1	0.54	88.3

[1] - Komline Sanderson Minifilter, vacuum
67.8 N/m^2 (20 in. Hg), polypropylene filter media

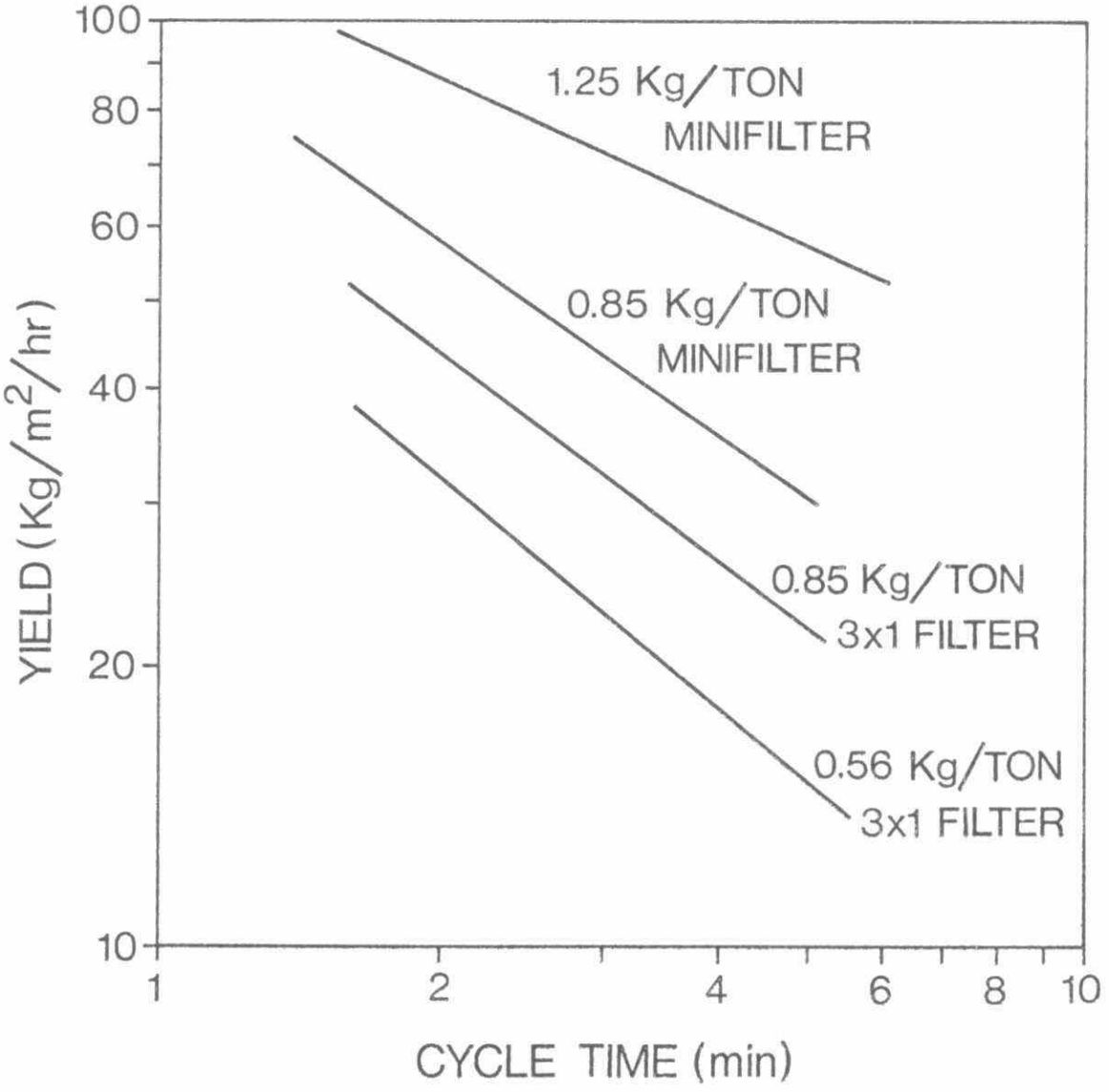

FIGURE 8. YIELD AS A FUNCTION OF CYCLE TIME AND POLYMER ADDITION

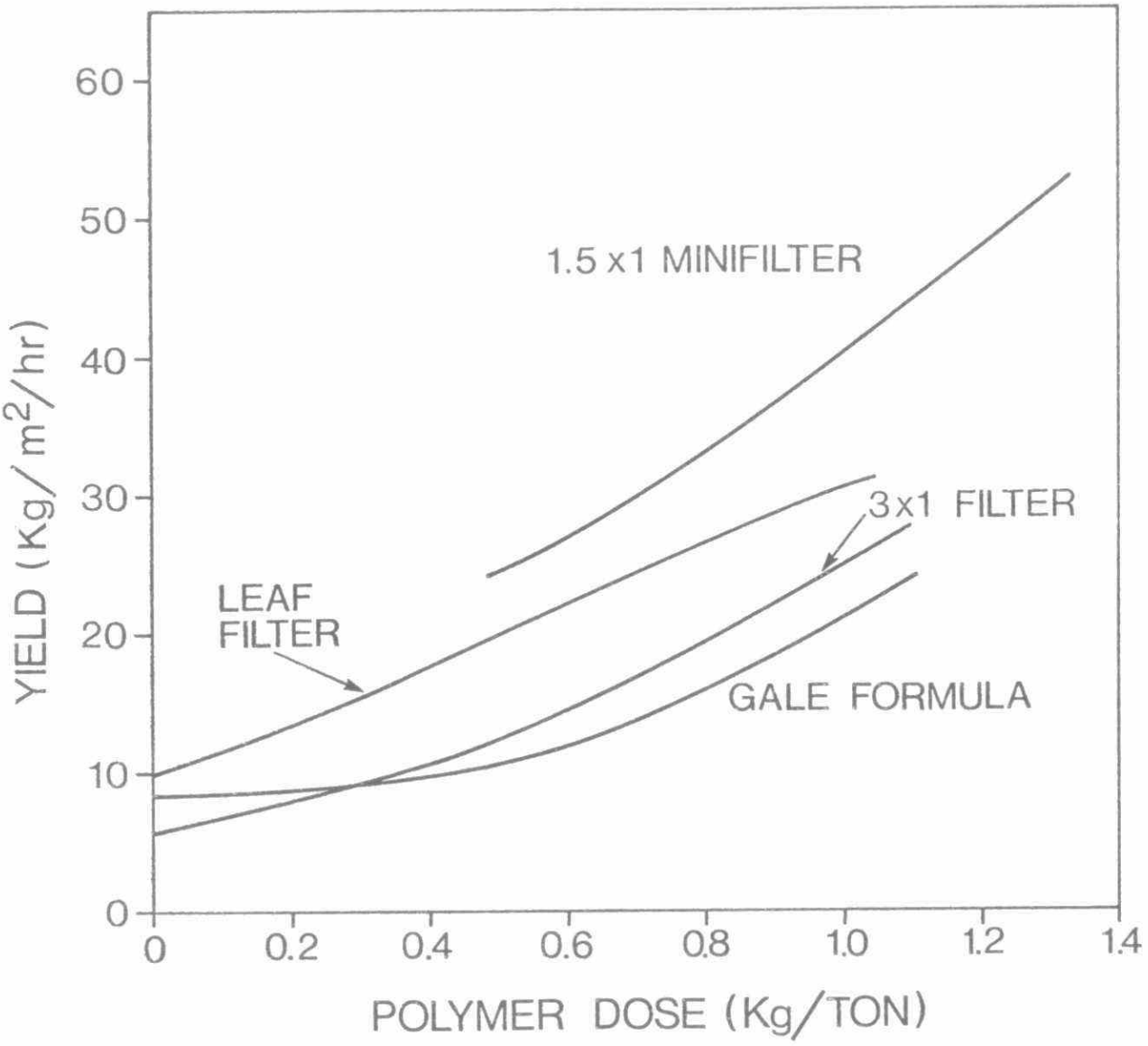

FIGURE 9. COMPARISON OF YIELDS OF FILTER LEAF, BUCHNER FUNNEL, AND 1.5 x 1 AND 3 x 1 VACUUM FILTERS

ACKNOWLEDGEMENTS

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CENTRIFUGES - TYPES AND APPLICATIONS

by
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My paper this morning will cover as much as possible in a very brief time the types of centrifuges now being used in waste treatment, the more suitable applications for each type, and something on scale-up for the different types. Centrifuges are now so well established in the field that I will not spend any time extolling their virtues. By may own unaudited account, there have been at least a thousand centrifuges sold on waste treatment in the past few years and probably half of these are on line. Since roughly a half of these are on municipal waste, considerable data have been generated and published, and it is relatively easy to find a nearby centrifuge to see if you are not familiar with them.

It seems well to start with a very generalized flow sheet of a waste treatment plant which could be either municipal or industrial. No one plant will have all of the sludges shown, but the intention is to show the range of sludges that can be produced in such plants and the types of centrifuges that would be applied for thickening or dewatering. Figure 1 shows the flow sheet, slthough it does not try to show all the possible combinations of sludges that can occur. It is assumed that some reasonable degree of degritting will remove the coarsest material from the sludges as this greatly reduces the abrasion on centrifuges as well as other equipment in the plant. Also, it is strongly recommended that masceration be included, eith on the plant influent or, more specifically, on the sludge before it enters the centrifuge. The step eliminates most problems arising from plugging of feed control valves, feed lines, or centrifuge feed zones. The flow sheet can be reviewed again at your leisure so I will just point out a few of the basic concepts.

TYPICAL APPLICATIONS OF SHARPLES CENTRIFUGES IN THICKENING WASTE AND DEWATERING SLUDGES

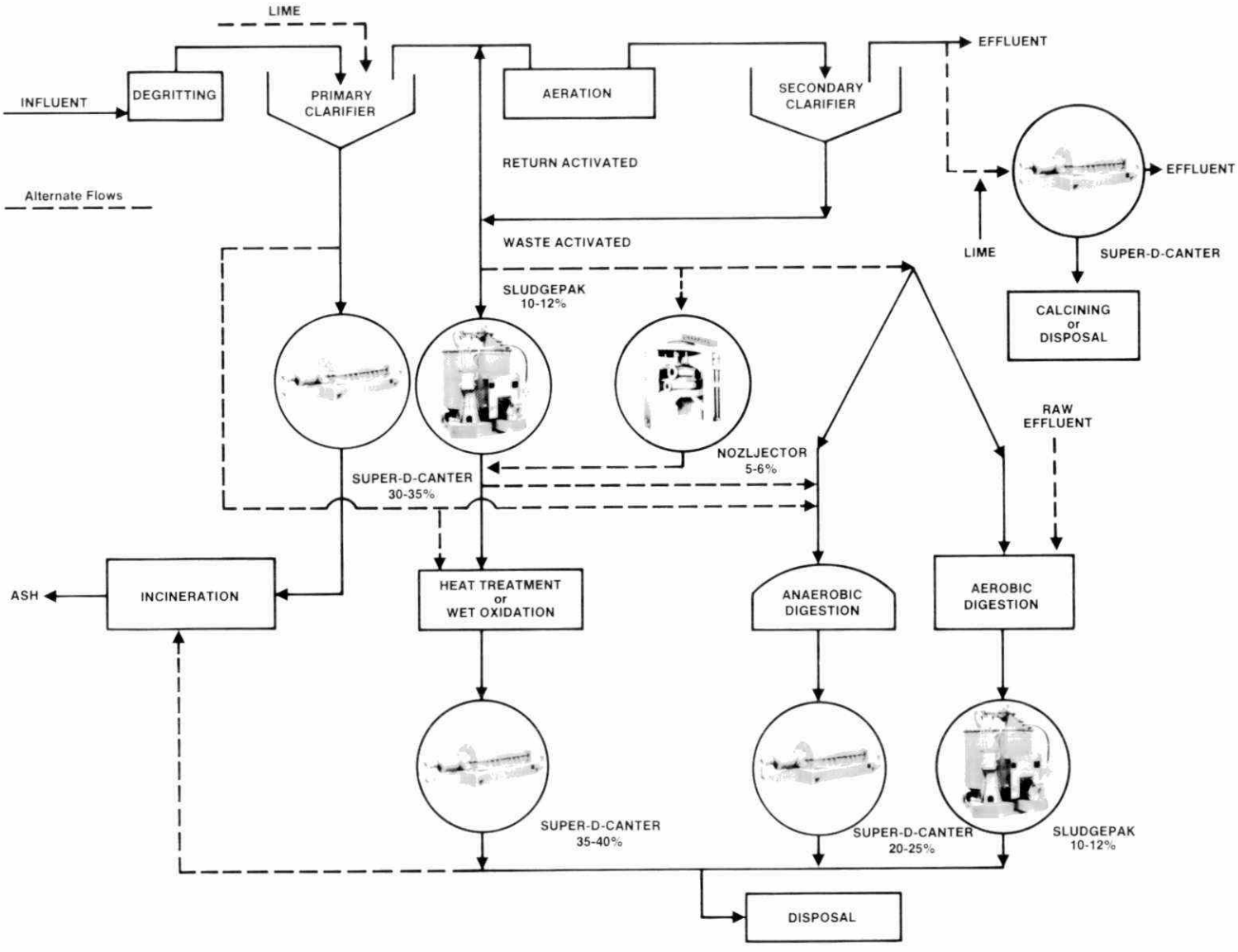


FIGURE 1

Initially it should be noted that all three types of centrifuges indicated on the flow sheet recover solids by sedimentation, but the three types differ in the means by which the solids are removed from the centrifuge bowl. The scroll type of centrifuge is designed to handle relatively heavy loads of the coarser types of solids and to produce generally dryer cakes than the other types of centrifuges on materials which show some free draining characteristics. This type is therefore used on almost all sludges containing primary solids or the solids that would normally settle in primary. Typical applications include raw primary sludge, raw primary cosettled with a return stream of waste activated, heat treatment or wet oxidation sludges containing primary solids, and anaerobic digested sludges. This same type would be used on sludges containing appreciable lime added for phosphate reduction, such as limed primary or limed primary cosettled with secondary activated or a tertiary lime sludge. Where secondary treatment consists of trickling filters or activated sludge, a waste activated is produced that may either be recycled to the primary clarifier for cosettling or may be thickened separately. There are sometimes advantages in dewatering the primary and secondary sludges separately by using different types of centrifuges and affecting an appreciable polymer saving. In some cases, such as for feed to a heat treatment unit or anaerobic digestor, the primary can be gravity-settled to the necessary 5-7% range while the waste secondary is thickened centrifugally without polymer. The flow sheet shows two types of centrifuges, an imperforate bowl with knife for cake removal or a disc centrifuge for simple thickening. These two centrifuges were originally introduced because the scroll centrifuge could not readily handle soft secondary sludges without appreciable polymer addition; both the imperforate bowl knifing unit and the disc centrifuge can give 85-90% recovery at good flow rates without the addition of polymer. The fact that scroll centrifuges would not satisfactorily handle activated sludges without excessive polymer was naturally a challenge to the vendors and very recent modifications have been made which now allow the scroll centrifuge to thicken many of the waste activated sludges without polymer at reasonable rates.

Aerobic digested primary plus secondary sludge or activated whole sewage without primary treatment (and with or without an aerobic digestion stage) are rather special types of sludge. The scroll centrifuge can handle these under some conditions, but generally the polymer requirements are high. For this reason the SludgePak, the imperforate bowl knifing centrifuge, has been very extensively applied to these sludges. Such sludges have generally arisen from relatively small plants so that the limited capacity of this centrifuge has been satisfactory.

Many other special combinations of sludges could be mentioned, for example, those resulting from alum or ferric salt addition to secondary or as pure tertiary treats. These may be handled in any of the three centrifuges and proper selection should be considered for each case. The important point to be remembered in regard to this range of applications is that centrifuges differ in their characteristics and it is highly advantageous to select the centrifuge or combination of centrifuges for most economic and efficient dewatering or thickening of sludge.

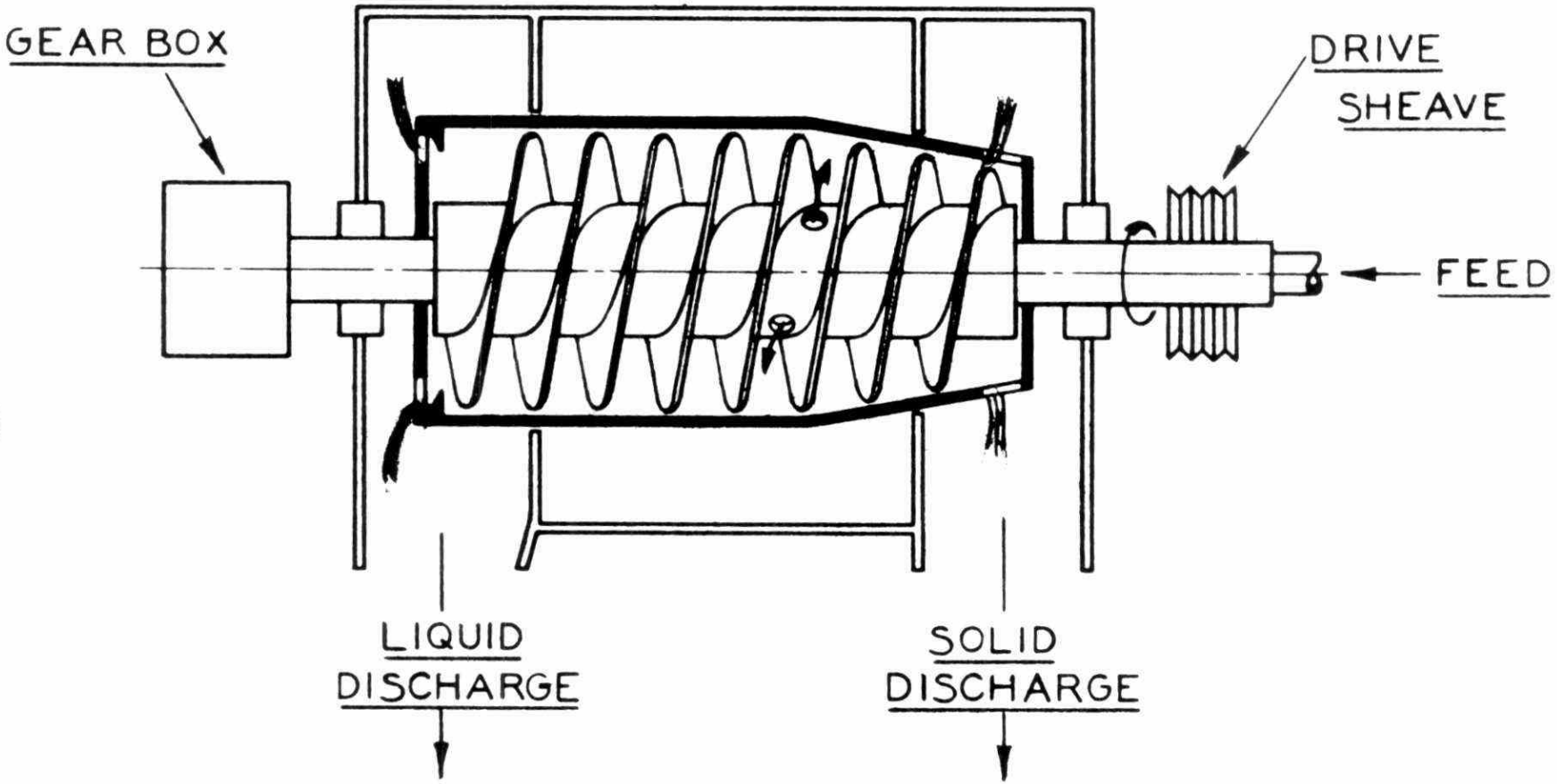
At this point let us consider some of the factors involved in scale-up of centrifuges and the type of accuracy to be expected. There is one rather interesting aspect of testing on sludges in the United States and Canada as opposed to the situation in Europe. In Europe there seems not to have been the proliferation of processes or the emphasis on adding biological or advanced treatment, so that it has often been possible to test the actual sludge which will eventually be handled by the centrifuge. On the other hand, in Canada and the United States, plant expansions frequently involve new processes and many of the plants are completely new, so that most testing has to be done on plants that are supposedly similar to the plant in which the centrifuges will finally operate. Fortunately, through a very extensive testing program over the past six years or so, basic curves have been established for various kinds of sludges. Even more fortunately, there does not seem to be such a broad variation in sludges produced by a particular process or method as to make it unfeasible to estimate satisfactorily what other plant performances will be. Some testing is still going on, but this is frequently more of a demonstration than it is a data-taking operation. Considerably less work has been done on sludges

containing alum than on the more standard sludges, to test data may be desirable if alum is present in appreciable quantities. As mentioned before, recent modifications to scroll centrifuges have permitted these to handle with little or no polymer some of the activated sludges, so current testing is aimed at determining what the limitations are for these units. On the whole, however, I believe that at least 80% of the bidding estimates are now made on sludges without tests. Scale-up has proven to be as consistent in handling wastes as it has in other types of centrifuge applications.

Sharples scales feed rate and clarification results on the basis of theory which has been thoroughly covered in various handbooks and test books; other vendors use their own versions of this theory. Unlike scale-up calculations, polymer response is not as consistent between different sludges in the usually acceptable American range of dosage, that is up to about 5 lb/t for 85-90% recovery. European practice tends to require 95% recovery or better so they have accepted the necessary higher dosages of polymer which may frequently run 6-8 lb/t. We have seen no problems developing in American plants operating at 85-90% recovery and the extra expenditure for polymer does not seem warranted.

Cake concentrations from centrifuges are dependent on the centrifugal acceleration applied, the compaction time in the bowl and the characteristics of the specific sludge; they are somewhat harder to predict, but a considerable background of information makes the estimates at least reasonable.

I will move along now to a discussion of the three types of centrifuges with a little more detail on each. The scroll centrifuge, which is referred to in our drawings as a Super-D-Canter, is the most generally used centrifuge and has the widest range of applications as discussed previously. Figure 2 is a schematic of a scroll centrifuge. As many engineers are familiar with this operation I will simply note that these units consist of a cylindrical section of varying length with a conical end; they contain a screw conveyor which turns at a speed slightly different from that of the bowl. This relative motion of the screw permits it to move solids which are sodimented to the bowl wall towards the conical end and out of the



IMPERFORATE BOWL CONVEYOR DISCHARGE CENTRIFUGE

FIGURE 2

solids discharge ports. The liquid phase is discharged as a clarified material through weirs at the other end of the centrifuge. Becuase these weirs are adjustable, the depth of the liquid in the bowl may be varied to give better clarification, simplify the scrolling problem of soft solids, give longer compaction time in the bowl or longer drainage time on the conical "beach", or reduce abrasion problems by reducing the differential speed. While the gear box provides a basic differential speed between the bowl and the scroll, an additional control on the pinion shaft of the gear train has proven extremely valuable in "fine tuning" the differential speed to help improve performance and reduce polymer requirements as sludge changes from day to day.

Some of the features of this design are shown better in Figure 3 which is a cutaway of a large unit frequently used in the municipal field. Feed is introduced at the far end thru the feed tube and enters the bowl through the conveyor discharge nozzles. The conveyor and adjustable effluent weirs are clearly shown. Super-D-Canters come in 14" and 25" diameters and a variety of lengths to suit the capacity requirements. Figure 4 is a picture of two of the 25" medium-length units installed. This shows the addy current backdrive on the end of the gear box for differential speed control as well as the lubricating system and the trouble-shooting panel. One of the earliest of these units was installed in a sewage plant at Intrenchment Creek near Atlanta, Ga. This plant was not originally available for testing so tests were run on a 14" P-3000 Super-D-Canter at the South River plant in Atlanta. South River has conventional primary with some trickling filters and mostly activated sludge, while Intrenchment Creek is primary plus high rate trickling filters. Both have two-stage anaerobic digestion and the sludges from the two have proven not to differ appreciably. The guarantee to Intrenchment Creek was made for a 90 GPM flow rate and Figure 5 shows a plot of recovery against polymer requirements at that rate. The solid curve is the prediction based on P-3000 testing at South River while the data points are for the P-5400 operation on the mixed digested sludge at Intrenchment Creek at several different pond depths. The scatter in the data obtained in the plant seems unfortunately to be the normal sort of scatter in plant operations but results clearly agree reasonably with the predicted curve.

Cutaway view of Model P-5400 illustrating typical features of horizontal models

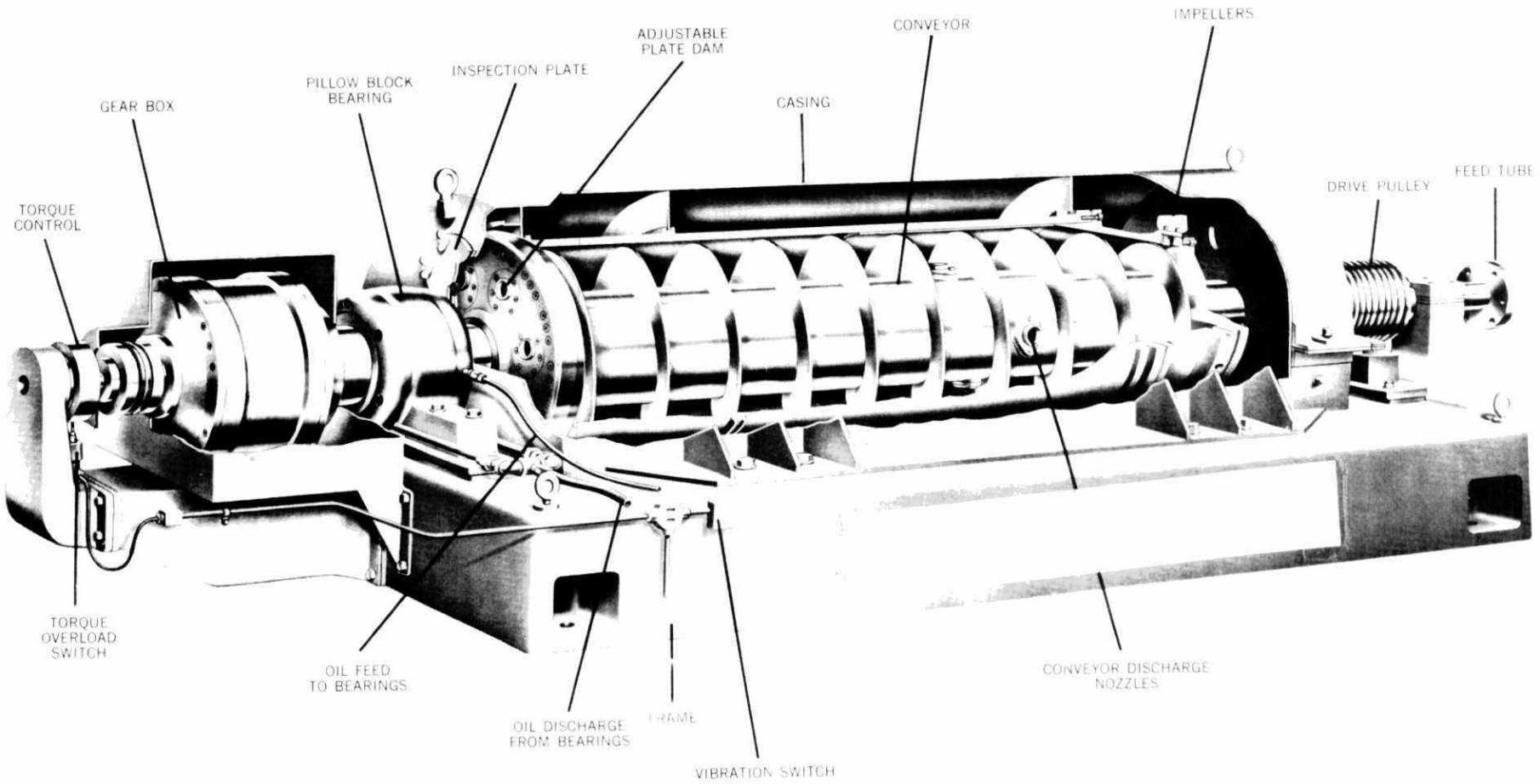


FIGURE 3

FIGURE 4

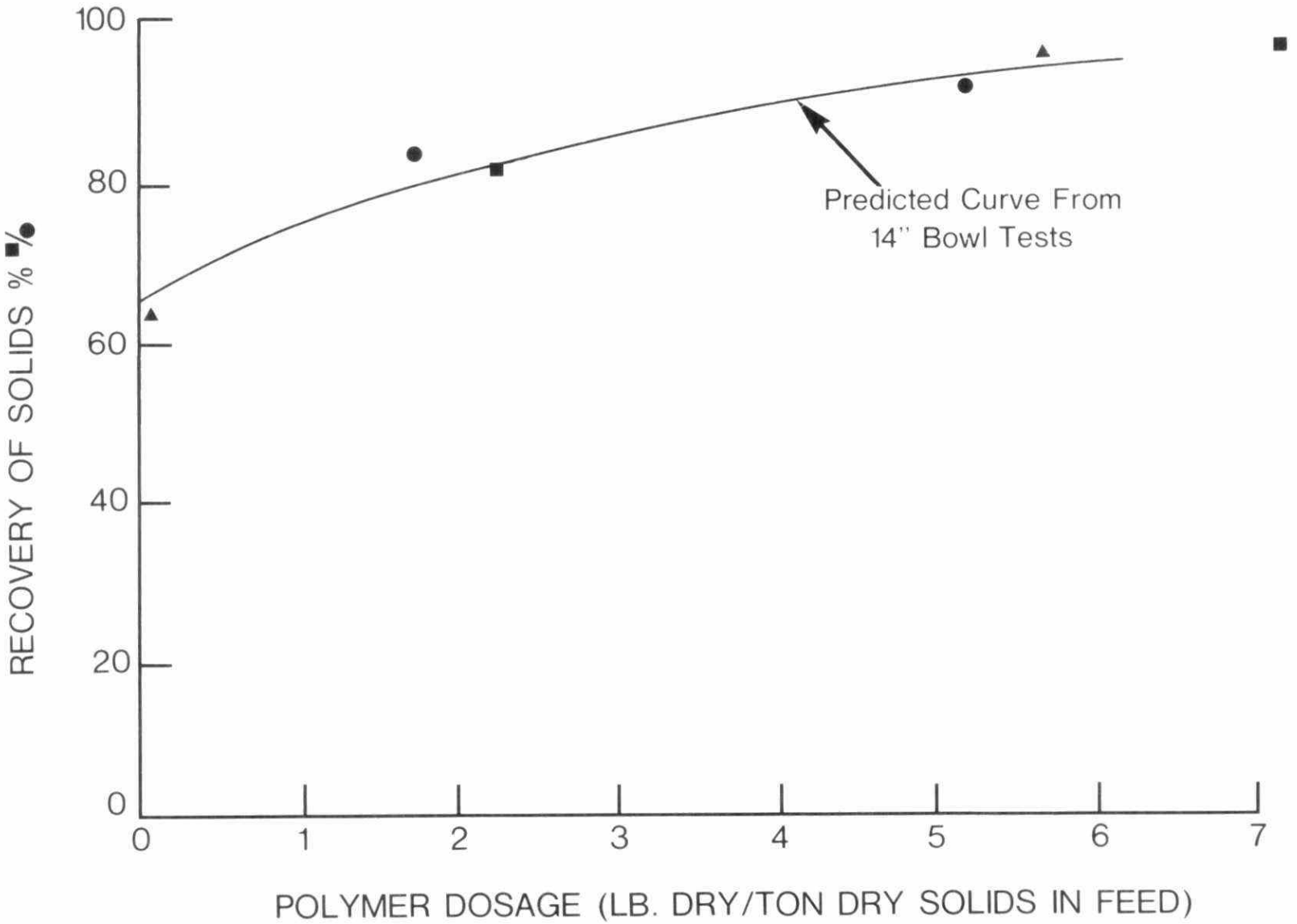


Figure 5. Operating Data on 25" Super-D-Canter at 90 USGPM, Mixed Digested, Intrenchment Creek, Atlanta, Ga.

An important factor is the abrasion resistance of these units and the type of hard-surfacing applied to the points were abrasion particularly occurs. There have been marked advances in both the hard-surfacing materials available and the techniques for their application; this technology is moving rapidly and further marked improvements again can be expected soon.

The imperforate bowl knifing centrifuge has had spectacular success in operating on biological sludges, either whole (including the primary solids) or secondary sludges. Alum sludges and biological sludges containing alum as an additive are also readily handled. While the largest of these is limited in flow rate to 35-50 USGPM, the real advantage is that they do not require polymer and generally gives recoveries of 90-95%. Cake concentrations vary markedly with different types of activated sludges. Some of the difficult industrial activateds will give cakes of only about 5% concentration while most municipal sludges give 9-11%; some oxygen-treated activateds and some industrial activateds, however, have gone as high as 15% solids or so.

Figure 6 is a cutaway of a SludgePak showing the outside covers, and the imperforate bowl with accelerator wheel near the bottom; feed is introduced through the large vertical pipe just off-center; cake is cut out by the knife on the right-hand side of the picture. Additionally, supernatant liquid and soft biological or alum cakes can be removed by the skimmer device which is seen just to the left of the feed pipe; the skimmer moves radially outward to intersect the cake and scoop it out. For knifing heavy solids, the bowl speed is reduced and the knife rotated into the bowl wall to cut out the cake and drop it through the open bottom of the basket. This unit is a modification of the old chemical industry basket centrifuges, but it has been fully automated to initiate a discharge cycle on the basis of cake buildup and is proving a very satisfactory centrifuge for waste treatment. It is a low speed unit and maintenance is extremely low.

Testing has usually been done on a 14" diameter laboratory unit and not too many opportunities have been available to follow in the same plant under the same operating conditions with a larger 40" or 48" diameter unit. Figure 7 shows some of the data that have been

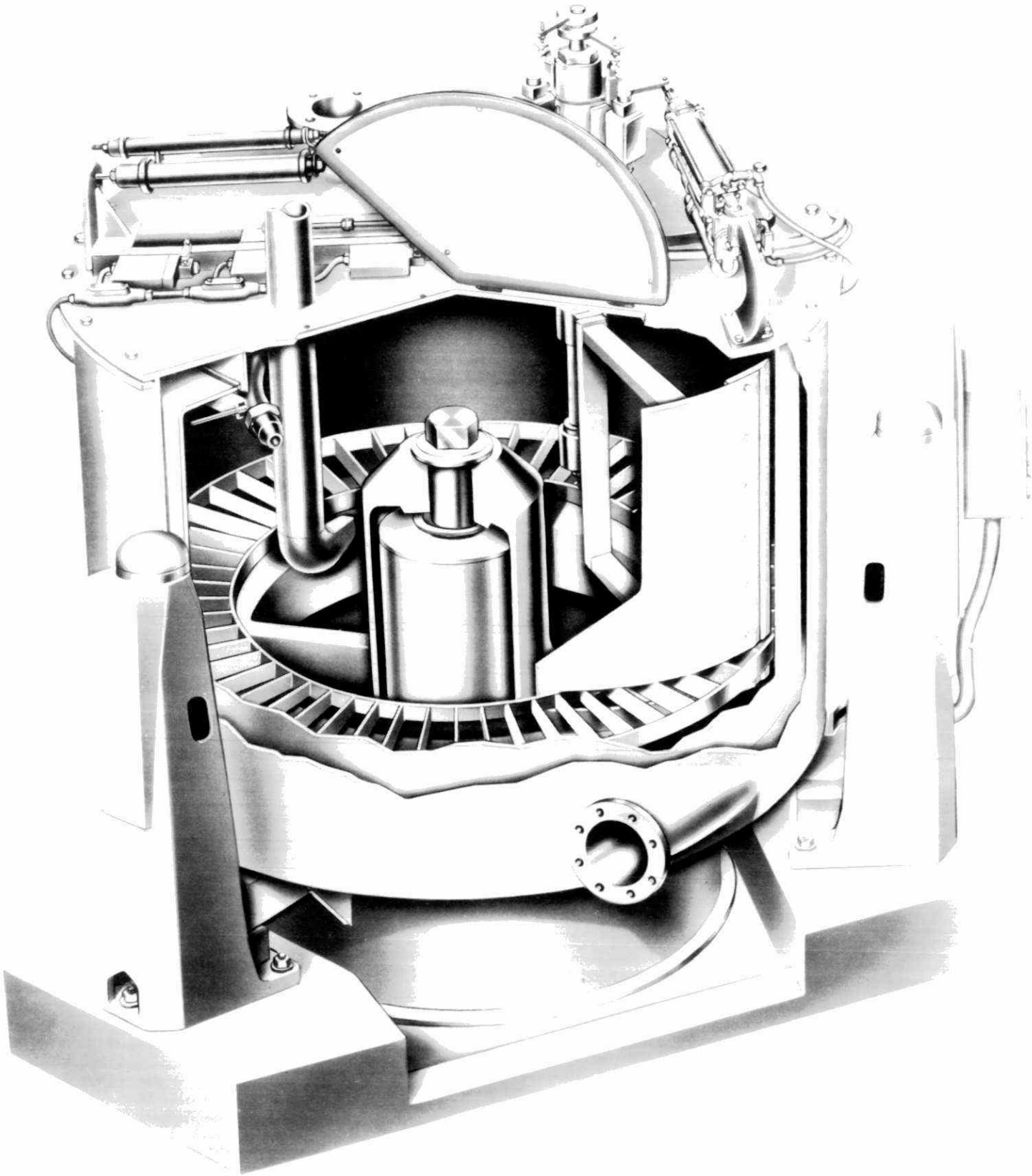


FIGURE 6. CUTAWAY OF A SLUDGEPAK.

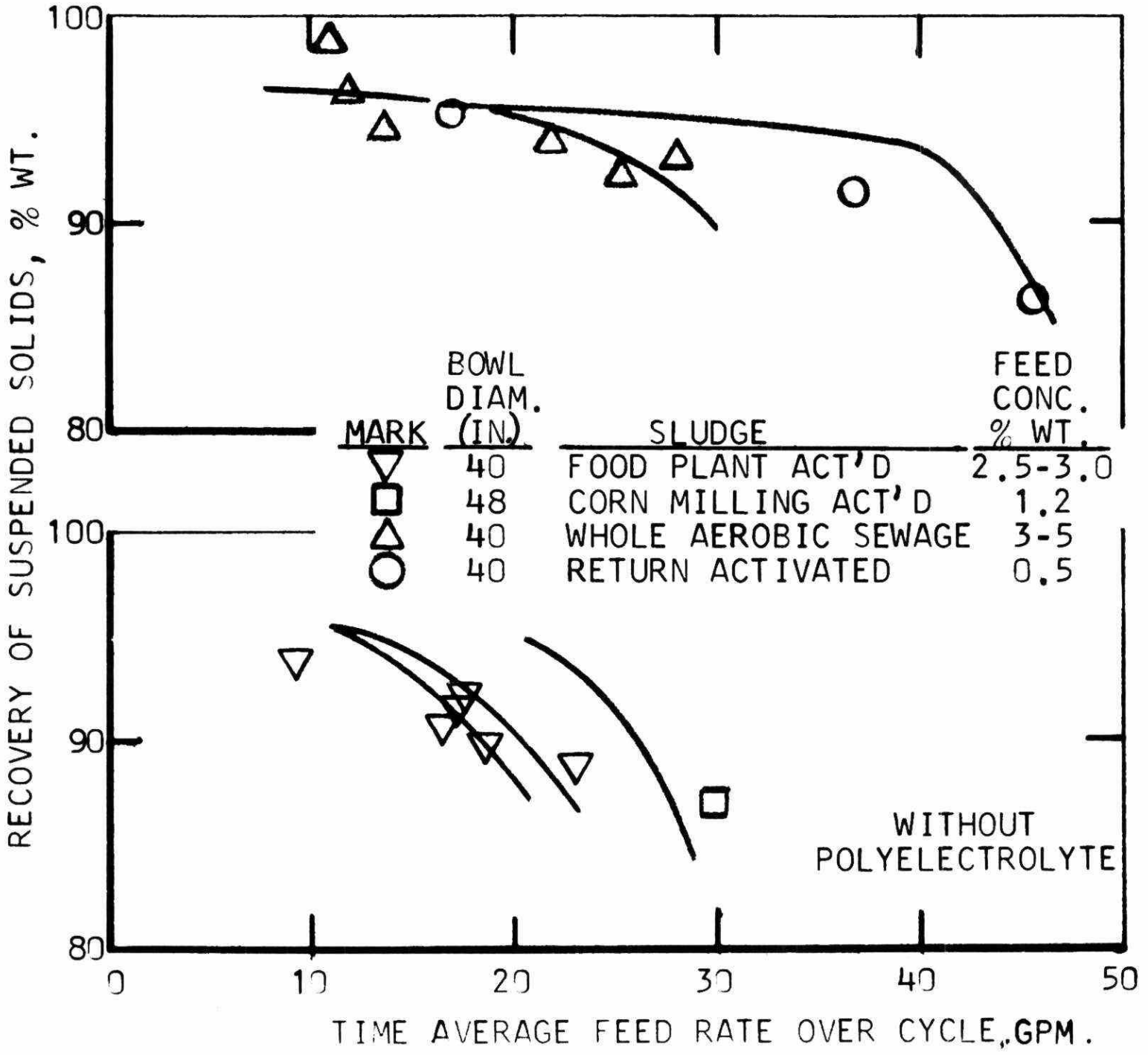

RECOVERY OF SUSPENDED SOLIDS, % WT.
100
90
80
100
90
80
0
10
20
30
40
50
TIME AVERAGE FEED RATE OVER CYCLE, GPM.
WITHOUT POLYELECTROLYTE
MARK
BOWL DIAM. (IN.)
SLUDGE
FEED CONC. % WT.
40 FOOD PLANT ACT'D 2.5-3.0
48 CORN MILLING ACT'D 1.2
40 WHOLE AEROBIC SEWAGE 3-5
40 RETURN ACTIVATED 0.5

FIGURE 7.

obtained. The solids curve in each case represents the predicted performance on the basis of tests in the 14" centrifuge; the data points represent the performance of a larger unit subsequently in operation at the plant. The agreement is generally quite good. It will be noted that the capacity for the activated sludge from the food plant is lower than from the municipal plants due to the more difficult sludge. Both a whole aerobic and a secondary waste activated are shown for the municipal plants.

The disc centrifuge has a rather specialized application in thickening of clean secondary activated sludge at relatively high rates. Figure 8 is a cutaway of a Nozljector disc centrifuge as installed in a number of industrial and municipal plants on secondary activated sludge. The heart of this unit is the set of conical slosely spaced discs through which the feed must pass before discharge from the bowl. The relatively high centrifugal forces and narrow spacing permit good clarification of even fine and low density particles. The solids slide along the bowl wall to the discharge nozzles and must be discharged as a discrete slurry that will flow through the rather small orifices of the nozzles. For this reason the feed must be well-cleaned and free of grit and fiber. This is also the reason that this unit is used for thickening to 5 or 6% concentration rather than for dewatering to the 10% or so concentration reached in the SludgePak. Figure 9 shows the operating flow range for a large disc centrifuge. Test data on secondary activated sludges were obtained at six plants in a 10" diameter disc centrifuge and scaled up to the anticipated operation of a larger unit; this range of operation is shown by the shaded area. Data later obtained on a 25" diameter bowl, the DH-5 Nozljector, are shown by the heavy solid line which is seen to be a good average of the scaled-up data.

In general, this type of centrifuge is installed to operate at 200 to 325 USGPM for recoveries of about 85 to 90% without the use of polymer. Underflow concentrations can be controlled and are feasibly held in the range of 4.5 to 6% concentration for feed concentrations from 0.3 to 1.5% by weight. As mentioned previously, it is very important to remove fibers and oversized gritty material from the feed in order that the disc spaces and discharge nozzles should not become plugged. With adequate screening and preparation, these bowls may go several

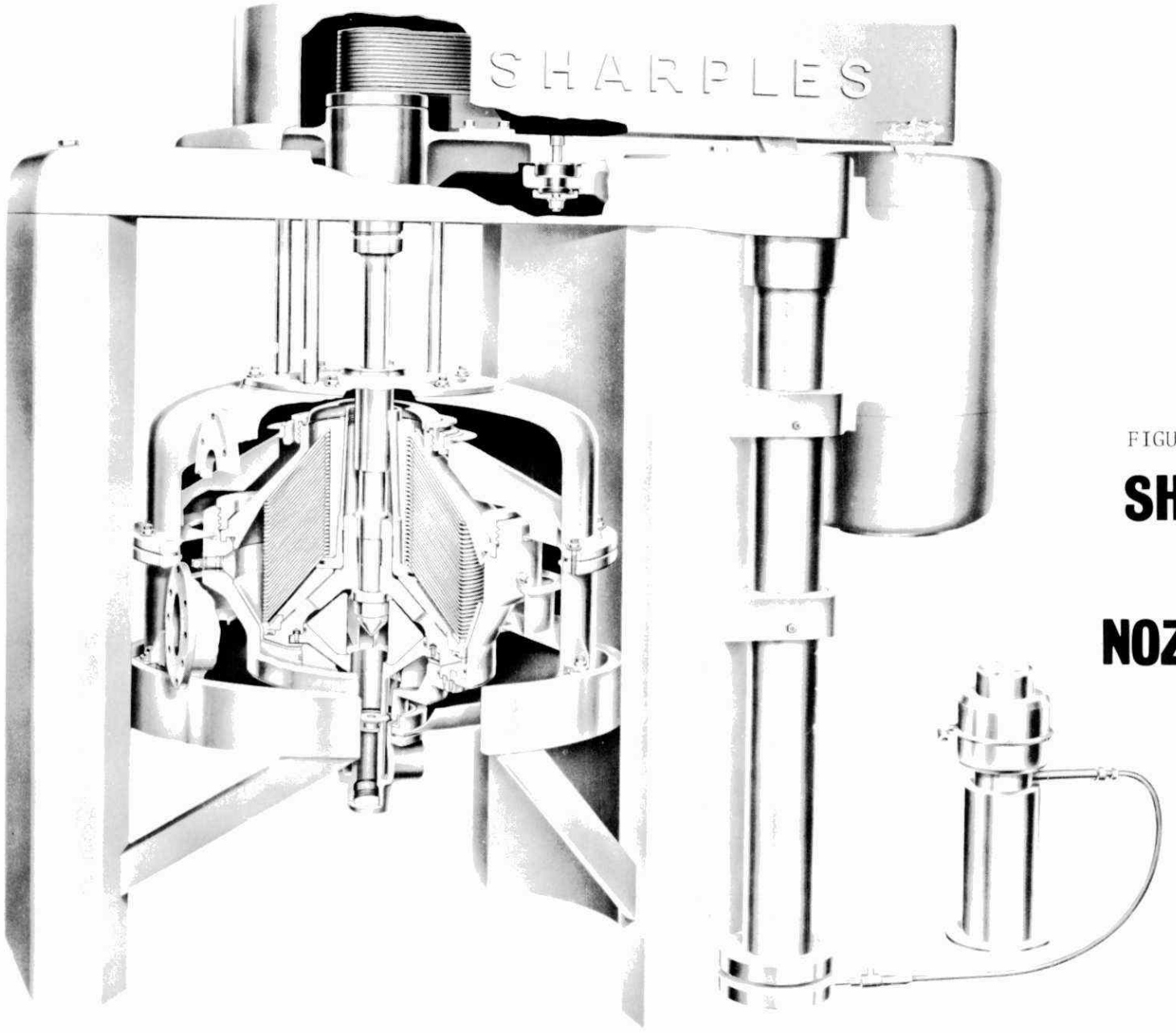


FIGURE 8.

SHARPLES DH-5 NOZLJECTOR®

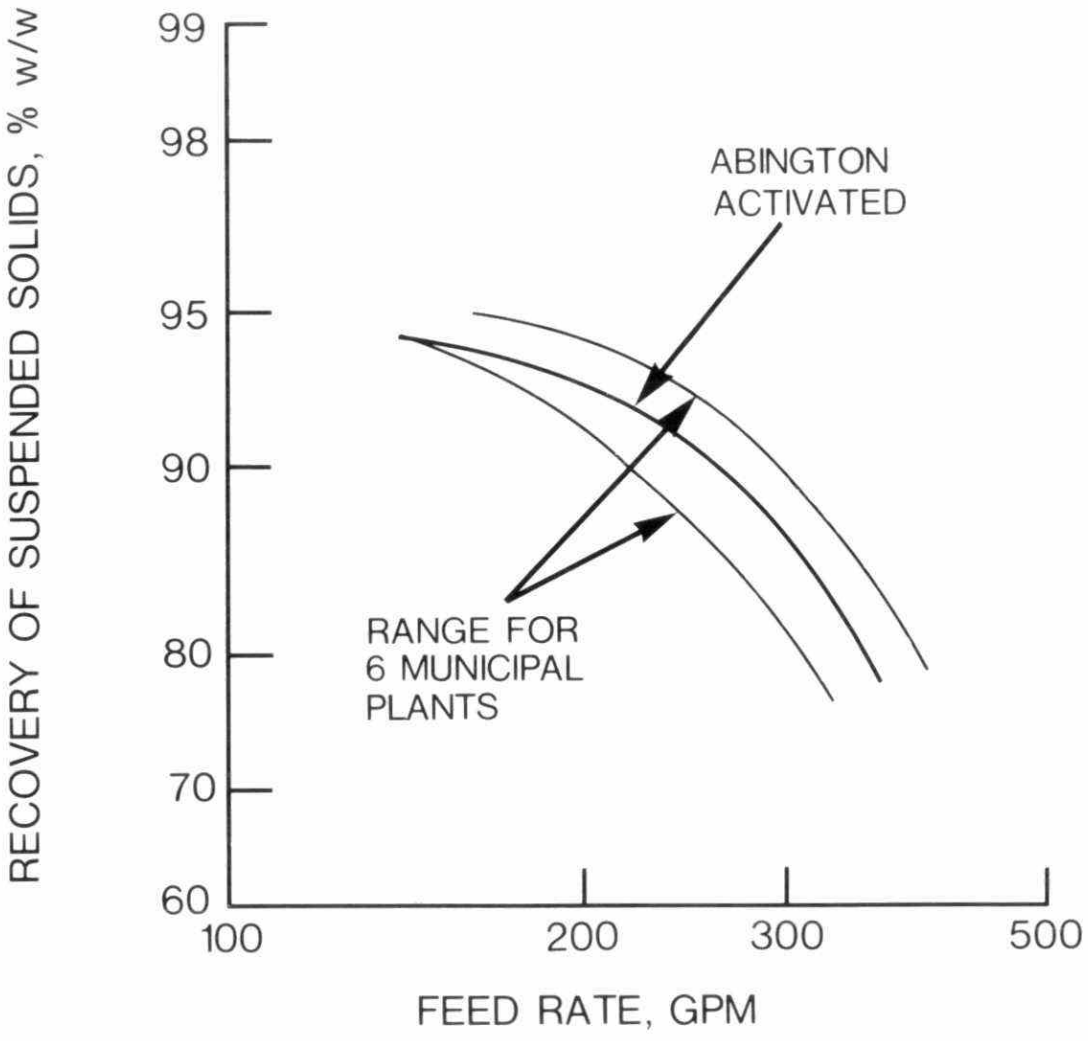


Figure 9. DH5 Capacities For Thickening Secondary Activated Sludge Up To 5½% Concentration

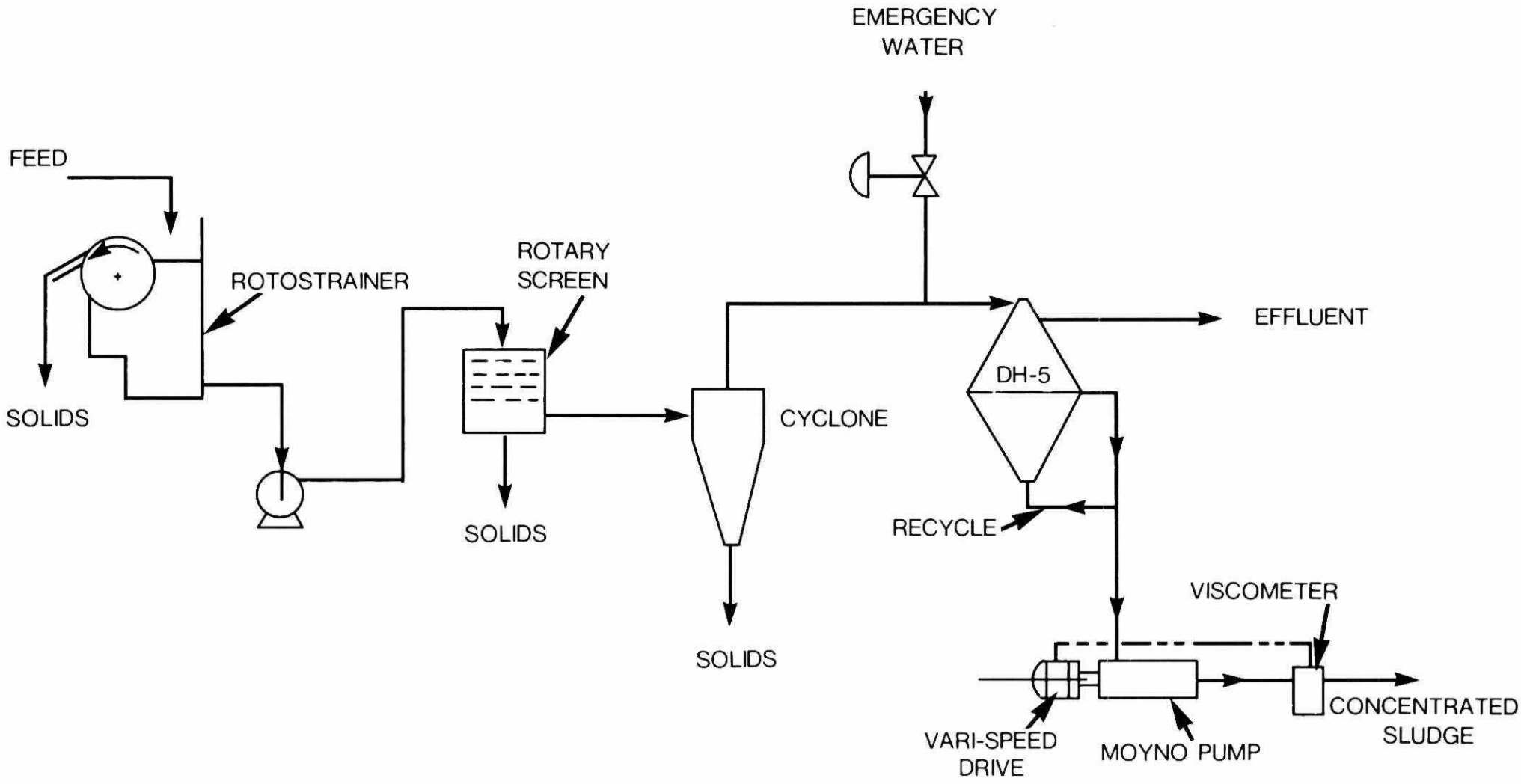


Figure 10. Recommended Feed System DH-5

months withoug the necessity of being opened. Initially, vibrating screens were used to remove the fiber and oversized material. It was generally reported that there would be no abrasive material in secondary activated sludge, but this was quickly proved to be false; there is always silt present and, under some conditions, a very considerable quantity of gritty material reaches the centrifuges. It was found that passing the feed through hydroclones, about 100 gpm in a 6" clone, did an excellent job of silt removal and practically eliminated the wear problem.

The vibrating screens proved to have high maintenance and their tendency to form small silts occasionally allowed the passage of fibrous material. Several different types of screens are now being used instead of vibrating screens for preliminary solids removal; these include both Rotostrainers and DSM screens. As shown in Figure 10, these should be followed by a cyclone for silt removal with a final rotating screen as a backup device; the latter cannot take a high loading but serves to remove the occasional fibers that pass through the preliminary screening. Feed concentrations and feed rates on activated may change considerably. It is entirely feasible to put a viscometer on the nozzle discharge and automate the rate at which a portion of this discharge is returned to the bowl to control the concentration of the nozzle discharge. Such instrumentation is neither necessary not desired at some plants, but it can be important if wide variations in feed are expected or if particularly close control of the discharge is required.

SLUDGE DEWATERING USING THE KRUGER CENTRIFUGE

by

L.P. Roe

The East Asiatic Company (Canada) Ltd.

INTRODUCTION

During the last ten years, solid bowl decanter centrifuges have been gaining increasing acceptance for the dewatering of sewage sludges. Their use has been common for some time in Scandinavia and the USA, and is now becoming common in Canada. The author knows of 13 sewage treatment plants in this country which are already using or are planning to use decanter centrifuges for sludge dewatering.

In it simplest form, the decanter centrifuge consists of a cylindrical-conical bowl, open at both ends, rotating about a horizontal axis. The sludge is introduced into the bowl through a stationary feed tube positioned along the bowl axis. Under the influence of the centrifugal force generated by the rotation of the bowl, an annular pool of sludge is formed against the bowl wall. The sludge pool is retained within the bowl by the reduced diameter conical section, at one end, and by a ring-shaped overflow weir at the other. The sludge solids settle to the bowl wall and a screw conveyor within the bowl moves the solids to the conical end where they are discharged. The separated water, or centrate, is discharged at the other end of the bowl over the ring-shaped weir. The inside diameter of this weir determines the depth of the sludge pool and is so arranged that a portion of the conical section of the bowl is above the level of the sludge pool. This section of the bowl is known as the beach. The sludge solids have to be scrolled up the beach and it is here that they are dewatered prior to being discharged from the centrifuge through the cake discharge ports.

HISTORY

The decanter centrifuge was the first used to dewater sewage sludges over 40 years ago and its advantages are now well known. It operates continuously and requires lettle operator attention. The sludge is pumped into the centrifuge, the centrate is discharged at one end, and the sludge cake at the other. It is simple and compact and little auxillary equipment is required, (a sludge feed pump, a polymer feed pump, and a conveying system for the sludge cake).

Unfortunately, the decanter centrifuge suffered from two major disadvantages:

1) The solids capture through the machine was poor. Typically, about 80-85% capture was achieved. The centrate contained high concentrations of fine solids which had to be recirculated back through the treatment plant. This continuous recirculation of fines resulted in a considerable increase in the load on the treatment plant, and the treatment efficiency tended to suffer. This was particularly evident at plants which were already operating at or above their design capacity. The concentration of fines in the sludge eventually reached equilibrium but there was an inevitable deterioration in the dewatering characteristics of the sludge being fed to the centrifuges.

2) The grit present in the sludge caused considerable abrasive wear on the solids conveying scroll. The scroll was coated with an abrasion-resistant alloy but this hard-surface coating had to be renewed frequently resulting in high maintenance costs and considerable downtime.

KRUGER CENTRIFUGE

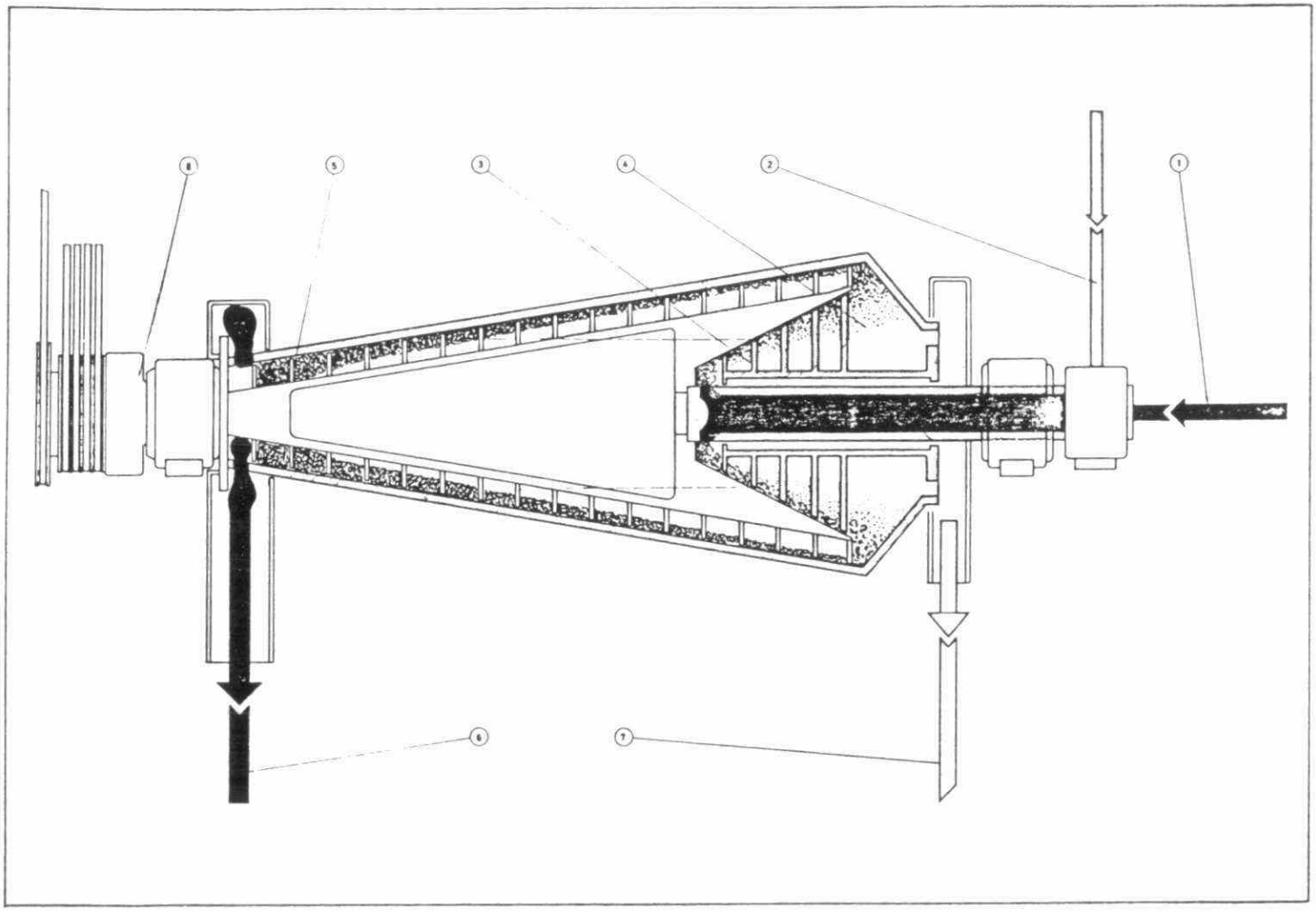
The Kruger Centrifuge was developed with the idea of overcoming the traditional disadvantages of the decanter centrifuge when dewatering sewage sludges. Development work started in 1965 and the final prototype machine, incorporating the main principals of the Kruger design, was produced in 1966. The first permanent centrifuge installation was put into operation in 1971 and there are now approximately 180 Kruger centrifuges in use throughout the world for the dewatering of sewage and industrial waste sludges.

It was felt that the main reason for the poor solids capture in decanter centrifuges was the way in which the incoming sludge was introduced and distributed into the sludge pool. In the conventional design, the incoming sludge was discharged directly from the feed tube into the pool and was accelerated virtually instantaneously up to the speed of the sludge already in the pool. Inevitably the sludge was subject to high shear forces which broke down the flocculant structure of the sludge particles and produced fines. These fines, being relatively much slower settling, were discharged in the centrate stream. A further problem with this method of feeding was the creation of a zone of severe turbulence in the sludge pool opposite the feed point. Solids which settled downstream of the feed point had to pass through this turbulent zone before they could be discharged from the centrifuge.

In recent years, synthetic polymer flocculant aids have been developed which are very effective in improving the performance of decanter centrifuges. They produce very large, fast-settling flocs and their use allows solids captures in excess of 99% to be achieved. However, when they are used, it is even more important that the flocculated sludge should not be subject to high shear forces or turbulence.

The flow path in the Kruger centrifuge is illustrated in Fig. 1. The incoming sludge is discharged from the stationary feed tube into a conical chamber within the solids conveying scroll.

FIGURE 1.



Key

1. Sludge Inlet
2. Polymer Solution Inlet
3. Inner Scroll
4. Separation Chamber
5. Solids Conveying Scroll
6. Sludge Cake Discharge
7. Centrate Discharge.
8. Cyclogear[1]

This chamber slopes outwards at a shallow angle and extends into the sludge pool. The sludge flows down the wall of this chamber, rather than being discharged directly into the pool. In this way, it is accelerated gradually up to speed and is distributed into the pool around the whole bowl circumference. An inner scroll within the conical chamber further improves the smooth acceleration and distribution of the incoming sludge. This inner scroll also prevents the accumulation of sludge solids on the chamber wall.

As you will see, the sludge solids, once settled against the bowl wall, are not disturbed by the incoming sludge and are dewatered and scrolled out of the centrifuge under quiescent conditions.

The abrasive wear in decanter centrifuges is caused by the grit present in sewage sludges. This wear occurs mainly on the solids conveying scroll and can be likened to the wear that takes place on the flights of an ordinary screw conveyor. In the case of a centrifuge scroll, however, the operating conditions are much more severe since the scroll has to convey the sludge solids up the slope of the conical section of the bowl against the g-force generated within the centrifuge. Factors affecting the severity of the abrasive wear are:

a) The amount of grit in the sludge. It has been found that scroll wear is considerably reduced when the sludge being dewatered is from a plant served by separated sewer systems or when an efficient degritting system is used.

b) The g-force at which the centrifuge operates. The higher the g-force, the greater will be the load on the scroll as it conveys the sludge solids out of the centrifuge.

c) The scroll differential speed.

Observation of the wear on the scroll under operating conditions tends to confirm the influence of g-force and scroll speed on scroll wear. Wear is more severe at the large diameter end of the scroll where both the g-force and the linear speed of the scroll flights are greatest. Kruger have endeavoured to reduce scroll wear by using a relatively low g-force and scroll differential speed in their centrifuge. Kruger centrifuges are operated at about 800 g's and never more than 1000 g's. Scroll speed is usually within the range 10 - 20 r.p.m.

Other areas where wear can be observed in decanter centrifuges are at locations where there is a high relative velocity between the centrifuge and the material being processed. Such areas are at the sludge inlet and the cake and centrate discharge points. With the Kruger feeding arrangement, the relative velocity between centrifuge and sludge is minimized. However, some wear does take place at the sludge inlet scroll. This wear is much less than on the main scroll since the scrolling action is assisted rather than opposed by the centrifugal force. The amount of wear at the cake and centrate discharges depends on the discharge velocities, which in turn depend on the centrifugal force in effect at these two locations. Obviously, the lower the g-force, the less will be the wear.

It is surprising that wear should occur at the centrate discharge since any grit present in the sludge would be discharged with the cake. Clearly, grit is not the only abrasive material present in sewage sludge. Wear at the centrate discharge was unusually severe at one particular centrifuge installation. The probable explanation was that the centrate contained a relatively high concentration of suspended solids.

PERFORMANCE

The performance that can be expected from the Kruger centrifuge when dewatering various types of sewage sludges, is given below. These performance figures are based on extensive operating data obtained from Kruger centrifuges. It should be noted that they are average figures and may vary up or down. Polymer consumption, in particular, can vary considerably from plant to plant even when the same type of sludge is being centrifuged.

The polymer consumptions quoted are those required in order to produce a centrate containing less than 1000 mg/l suspended solids.

PRIMARY SLUDGE (RAW OR DIGESTED)

Suspended Solids Concentrations

Sludge:	6% by wt.
Cake:	25% by wt.
Centrate:	1000 mg/l

Polymer consumption: 3.5 - 4 lb/Ton dry sludge solids.

NON-DIGESTED MIXED PRIMARY & WASTE ACTIVATED SLUDGE

Suspended Solids Concentrations

Sludge:	5% by wt.
Cake:	24% by wt.
Centrate:	1000 mg/l

Polymer Consumption: 4 lb/Ton dry sludge solids.

DIGESTED MIXED PRIMARY & WASTE ACTIVATED SLUDGE

Suspended Solids Concentrations

Sludge:	4% by wt.
Cake:	22% by wt.
Centrate:	1000 mg/l

Polymer Consumption: 5 lb/Ton dry sludge solids.

AEROBICALLY DIGESTED SLUDGE (FROM PLANT WITHOUT PRIMARY CLARIFIERS).

Suspended Solids Concentrations

Sludge:	1.5% by wt.
Cake:	13% by wt.
Centrate:	1000 mg/l

Polymer Consumption: 6 lb/Ton dry sludge solids.

WASTE ACTIVATED SLUDGE

Suspended Solids Concentrations

Sludge:	1% by wt.
Cake:	12% by wt.
Centrate:	1000 mg/l

Polymer Consumption: 11 lb/Ton dry sludge solids.

DIGESTED PRIMARY & WASTE ACTIVATED & ALUM SLUDGE

Suspended Solids Concentrations

Sludge:	3.5% by wt.
Cake:	19% by wt.
Centrate:	1000 mg/l

Polymer Consumption: 6 lb/Ton dry sludge solids.

FACTORS AFFECTING CENTRIFUGE PERFORMANCE

Sludge

a) Solids Concentration.

As one would expect, sludges which thicken readily to a high solids concentration under the influence of gravity alone, will be more easy to centrifuge than sludges which do not. A drier cake will be produced and the polymer consumption will be lower.

b) Sludge Condition

It has been found that raw sludges which are held under anaerobic conditions for any length of time become more difficult to dewater. This applies particularly to activated sludge and to mixed primary and activated sludge.

This factor should be borne in mind when attempts are made to increase the sludge solids concentration by holding it in the clarifiers or thickening tanks for extended periods.

c) Surface Aerators

Activated sludge from plants using surface aerators tends to be more difficult to dewater than sludge from plants using diffused air aeration. In particular, polymer consumption is higher and centrifuge capacity is lower.

The probable explanation is that the sludge is more broken up and so is slower settling and requires more polymer to flocculate it.

d) Sludge Temperature

Centrifuge performance improves as the sludge temperature increases. Possible explanations are the lower sludge viscosity and surface tension and a faster reaction between the sludge and polymer.

The effect of temperature is particularly noticeable when dewatering heat treated sludge or sludge drawn directly from a heated digester.

Polymer

a) Type of Polymer

Polymers used in the dewatering of sewage sludges are generally of the cationic type. Having said that, the only way to find the most effective polymer for a particular sludge is by trial and error under actual operating conditions. A polymer which works very well with one sludge may be completely ineffective with the same type of sludge from another plant. It should be noted also that a polymer which is found to be the most effective in one design of centrifuge need not be the most effective in a centrifuge of different design even though the same sludge is being dewatered.

For some applications, a combination of two polymers, one anionic and one cationic, can be the only effective method of flocculation. This is often the case with sludges containing high concentrations of metals. The anionic polymer is added first, ahead of the centrifuge, while the cationic polymer is added at the centrifuge. This system requires more operator attention and can result in wasteage of polymer if not controlled carefully.

Anionic polymers are rarely used for the flocculation of sewage sludges.

b) Polymer Solution Concentration

Polymer solution concentrations in the order of 0.1% are normally used. Lower concentrations can increase the polymer effectiveness. Against this one has to consider the increased size of the polymer solution tanks and closing pumps.

Proper preparation and handling of the polymer solution is important in order to obtain the maximum flocculating effect from the polymer. Polymer cost represents a considerable portion of the total cost of sludge dewatering.

Centrifuge

The following variables are available when operating a decanter centrifuge.

a) Sludge Feedrate
b) Polymer Feedrate
c) Pool Depth
d) Scroll Differential Speed
e) Centrifuge Speed

Generally, only the first two are changed once a centrifuge has been set up to dewater a particular sludge.

a) Sludge Feedrate

The pump feeding the centrifuge usually has a variable speed drive allowing easy regulation of the sludge feedrate.

Reduction in feedrate increases the retention time in the sludge pool and so solids capture is improved, i.e. a cleaner centrate is produced. Indirectly, the polymer dose, in terms of lb/Ton dry sludge solids, will also be increased and this will further improve centrate clarity and, at the same time, improve cake dryness.

If, after reduction of the sludge feedrate, the polymer feedrate is also reduced so as to give the same centrate clarity as before, the net result will be a reduction in the "lb/Ton" polymer consumption.

Operating the centrifuge at reduced capacity will reduce polymer costs.

b) Polymer Feedrate

Not surprisingly, increasing the polymer feedrate will give a cleaner centrate and a drier cake.

A large excess of polymer sometimes results in a dirtier centrate. The excess polymer causes foaming inside the centrifuge and some solids are discharged with the centrate because of a flotation effect.

c) Pool Depth

All decanter centrifuges have provision for adjustment of the pool depth. In the Kruger machine, the adjustment is obtained by using overflow rings of different diameters.

Increasing the pool depth increases the pool volume and hence the sludge retention time. Solids capture will be improved resulting in a cleaner centrate. At the other end of the machine, however, the length of the conical section of the bowl above the sludge level (the drying beach) is reduced. Consequently a wetter cake will be produced.

Selection of the pool depth requires a compromise between cake dryness and centrate clarity.

d) Scroll Differential Speed

In the Kruger centrifuge, a separate V-belt is used to drive the scroll and so the scroll speed can be changed by using different size V-belt pulleys.

Increasing the scroll speed means that the sludge solids spend a shorter time on the drying beach. A wetter cake results.

Reduction of the scroll speed will have the converse effect and give a drier cake. However, too low a scroll speed will limit the solids conveying capacity of the centrifuge. Ideally, the scroll speed should be adjusted so that the solids conveying capacity is equal to the solids input plus a suitable safety margin to allow for possible upward fluctuations in the sludge solids content.

e) Centrifuge Speed

Decanter centrifuges are usually driven by a fixed motor and V-belt drive. Centrifuge speed is changed by using different diameter pulleys at the drive motor.

The Kruger centrifuge is operated at speeds which will give a centrifugal force within the range 400 to 1000 g's. Increasing the centrifuge speed will increase the g-force and this will tend to improve both separation in the sludge pool and drainage of the sludge cake at the drying beach. On the other hand, turbulence in the sludge pool tends to increase since it is more difficult to obtain smooth acceleration of

the incoming sludge. As a result solids capture may deteriorate. Also, it becomes more difficult to convey the sludge cake out of the machine against the higher g-force. The can result in a reduction in the solids handling capacity of the centrifuge in the same way as using too low a scroll speed. With some types of sludge, operation at too high a g-force can effectively reduce the solids conveying capacity to zero. In this situation, the sludge solids slide back down the conical section of the bowl as fast as they are conveyed up it by the scroll.

Selection of centrifuge speed necessitates a compromise between machine capacity and cake dryness on the one hand and solids capture/polymer consumption, maintenance and power consumption on the other.

CANADIAN EXPERIENCE

The Kruger centrifuge was first introduced into Canada early in 1970. During the last four years, sludge dewatering investigations using a Kruger centrifuge have been carried out at various sewage treatment plants in Brampton, Simcoe, Clarkson, London, Windsor, Burlington, Sudbury, Leamington, Kingston and Cornwall.

At Simcoe and Brampton, the sludge to be dewatered was a digested mixture of primary and waste activated sludge. In both cases, it was found that a two polymer system (anionic and cationic) was required. At Clarkson where the same type of sludge was being dewatered a single cationic polymer was used. In all three cases, centrifuge performance was generally as expected.

The sludges at London and Leamington were both waste activated sludge from surface aeration systems. These trials demonstrated the relatively poor dewatering characteristics of this type of sludge. As expected, polymer consumption was high and centrifuge capacity was low. It did prove possible, however, to obtain very clean centrates, containing around 100 mg/l suspended solids.

Waste activated sludge from diffused air aeration systems was dewatered at Burlington and Sudbury. These sludges were easier to dewater and polymer consumption was considerably lower. At Sudbury, the effect of centrifugal force on solids conveying capacity was demonstrated. Initially the centrifuge was operated at approximately 950 g's and it proved

impossible to convey the sludge cake out of the centrifuge. At 750 g's very good results were obtained.

At Windsor, sludge dewatering trials were run at the same time as phosphate removal investigations were being carried out at the plant. The sludge to be dewatered was a mixture of raw primary and waste activated sludge. It is interesting to note that the sludge containing alum proved easier to dewater than sludge without alum.

The Kingston and Cornwall sludge dewatering trials were on primary digested sludge. This is perhaps the easiest type of sludge to dewater, and the results obtained at both plants were excellent. The beneficial effect of relatively high sludge temperature on the sludge dewatering characteristics could be seen at these two plants.

Permanent installations of Kruger centrifuges, which were not preceded by trials with a mobile machine, are at treatment plants in Scarborough and Chatham.

At Scarborough, the sludge is a digested mixture of primary and waste activated sludge. Centrifuge performance is not as good as could normally be expected with this type of sludge. Possible explanations are the use of surface aerators in the activated sludge system and the relatively low temperature of the sludge. Also, laboratory and full scale tests have indicated that a different polymer would improve performance to some extent.

At Chatham, the sludge again is a digested mixture of primary and waste activated sludge except that ferric chloride is being added ahead of the primary clarifiers for phosphate removal. The aeration system is diffused air and the sludge is relatively warm. Centrifuge performance is better than expected.

Centrifuge trials have been carried out at two tanneries in Ontario. At the first tannery it proved impossible to find a method of operation which would give consistent centrifuge performance. The composition of the sludge varied widely from day to day and the polymer being used, a cationic type, sometimes gave excellent flocculation and on other days had no visible effect. on the sludge at all.

The trials at the second tannery were more successful. The sludge here contained a high concentration of lime which probably gave

it more stable dewatering characteristics. A combination of alum and an anionic polymer consistently gave good flocculation. The centrifuge produced a very dry cake and a clean centrate. However, the cost of alum and polymer was extremely high.

There is one permanent Kruger centrifuge installation at a plating shop in Ontario. The sludge is a mixture of metal hydroxides and the centrifuge has proved an excellent method of dewatering this type of sludge. An anionic polymer is used for flocculation.

MAINTENANCE

The decanter centrifuge is basically a very simple machine. It contains only two major moving parts, the bowl and the scroll. As previously mentioned, the component requiring the most maintenance is the solid conveying scroll. The coating of hard surface metal on the scroll requires periodic renewal.

With the Kruger centrifuge, it has been found that the life of the hard surface coating is approximately 5-6,000 hours when dewatering sewage sludges. This is an average figure and the actual life depends on such factors as the amount of grit in the sludge, the operating g-force and the scroll speed.

When renewal of the hard-surfacing is required, the scroll assembly must be removed from the centrifuge. After application of a fresh layer of hard surface metal, the excess metal is ground off so that the scroll is restored to its original dimensions.

The scroll assembly then has to be dynamically balanced before being reinstalled in the centrifuge.

Resurfacing a scroll can be a lengthy operation, especially since at least part of the work, e.g. the dynamic balancing, has to be done at an outside workshop. Where standby dewatering capacity is not available, a spare scroll assemby should be held in stock. Centrifuge downtime is then limited to the time required to remove the old scroll and install the new one, a matter of hours rather than weeks.

The Kruger centrifuge contains two sets of bearings, one set for the scroll, and the main bearings which support the complete centrifuge rotor.

Because of the size of the scroll shaft, the scroll bearings are necessarily very much oversized.

Also, these bearings run at very low speed, 10-20 rpm (the scroll defferential speed). They are grease-lubricated and, because of their low speed, they can be run with the bearing housings completely full of grease. In this way, any sludge or water is effectively prevented from entering the bearing housings. The scroll bearings are not normally a high maintenance item.

The main bearings run at the full centrifuge speed and so cannot be over-lubricated in the same way as the scroll bearings. Premature failure of the bearings was a problem with the older design Kruger centrifuges. Invariably, failure was caused by the entry of water or dirt into the bearing housing. About a year ago, Kruger redesigned the sealing system for the main bearings and since that time, premature bearing failure has not been a problem.

The scroll drive Cyclogear requires no maintenance apart from periodic changing of the lubricating oil. Experience has shown that the gear has a very extended life.

VACUUM DEWATERING OF SEWAGE SLUDGE

by

Geoffry D. Kemp

Komline-Sanderson Limited

We have prepared this paper in part as a report from the field on the vacuum dewatering of sewage sludges. There are approximately 40 vacuum filters operating today on a variety of sewage sludges at plants in Ontario. Sludges dewatered include raw sludge conditioned with ferric chloride and lime, anaerobically digested sludge conditioned with polyelectrolytes or ferric chloride and lime, and one plant has started to dewater thickened waste activated sludge conditioned with polyelectrolyte.

There will shortly be one plant dewatering thermally treated sludge with no chemical treatment.

With reference to some colour slides, I wish to briefly illustrate the principle of the vacuum filter.

The vacuum filter consists of a cylindrical drum, the surface of which is divided into a number of equal sections and which is covered with a filter medium. Each section has one or more pipes which connect the trailing edge of the section with a central valve through which the filtrate is removed.

The drum turns in bearings at each end and is submerged in a vat to between 25% and 37% of its circumference. As the drum rotates, each sector or compartment of the drum surface is submerged into the sludge. When the compartment is submerged it is subjected to a vacuum which draws the liquid from the slurry whilst the solids are retained on the filter medium.

During the time the compartment is submerged, liquid is being removed from the slurry. After the compartment emerges from the slurry until the filter medium separates from the drum, liquid is being removed from the filter cake on the drum surface. The lower of the two outlets on the filter valve, therefore, carries water whereas the upper valve has a large amount of air as well as some filtrate.

The filter medium is used to transport the filter cake to a point where it can be discharged onto a conveyer.

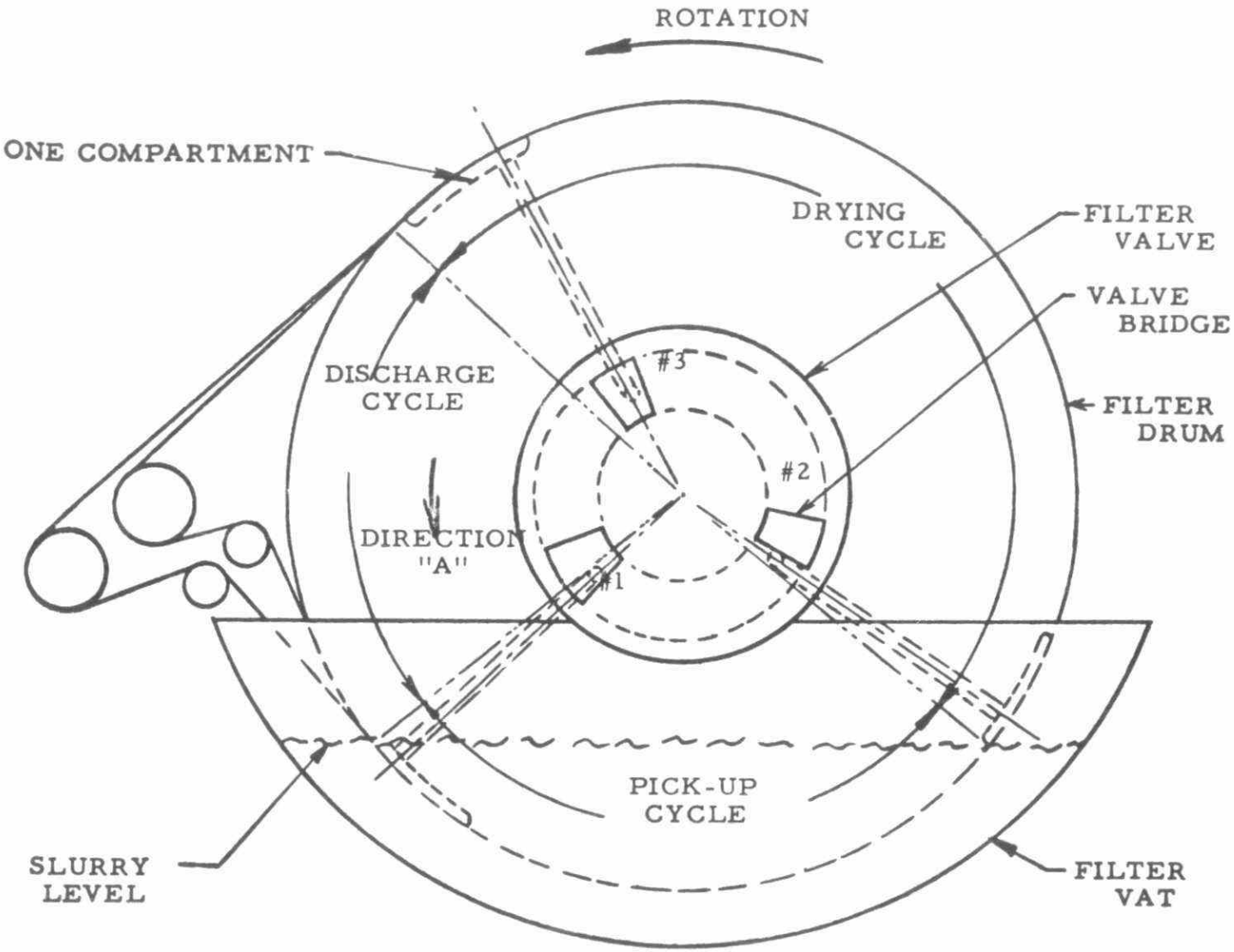

ROTATION
ONE COMPARTMENT
DRYING CYCLE
FILTER VALVE
VALVE BRIDGE
DISCHARGE CYCLE
#3
FILTER DRUM
#2
DIRECTION "A"
#1
PICK-UP CYCLE
SLURRY LEVEL
FILTER VAT

FIGURE 1.

The filter medium is then washed and returned to the filtering position on the drum.

The majority of filters in Ontario employ stainless steel coilsprings as the filter medium. The springs ride on each other and then directly on the drum face.

Drainage channels are provided between the springs allowing the filtrate to be collected in a single cross channel on the trailing edge of each compartment.

The other filter medium employed is a fabric which is supported away from the drum face by a plastic drainage grid.

The filter media used on sewage treatment vacuum filters generally are of an open nature as the filtered solids readily form a filter cake by bridging of the openings without loss of fine particles to the filtrate lines. Generally speaking, endless belt filters use a fabric having a thread count between 40 and 60 threads per inch which is close to the 5% open area presented by the Coilfilter medium. The use of a finer weave will result in lower yields and more difficult operation as the cloth will become progressively blinded.

The filtrate, after collecting at the valve in the centre of the drum, is piped to a vacuum receiver or water separator prior to discharge to the head of the plant.

It is recommended that the sludge be fed to the filters using positive displacement pumps or other devices which will permit the flow of sludge to the machine to be easily measured and controlled.

When operating a vacuum filter, the object is to achieve the dryest filter cake at the highest drum speed whilst using the least amount of coagulent. The first step is to ascertain the most economical dosage of coagulent and for this purpose we recommend the use of a Buechner Funnel Test Kit. A 100 ml. sample of conditioned sludge is poured into the funnel and the time is recorded for the filter cake to crack and the vacuum to break.

The proportion of coagulent is varied until the vacuum break is found occur, in the case of raw sludge at 70 seconds. The sludge feed pump and chemical feed pumps are then adjusted to provide the same ratio of sludge to coagulent as used in the test.

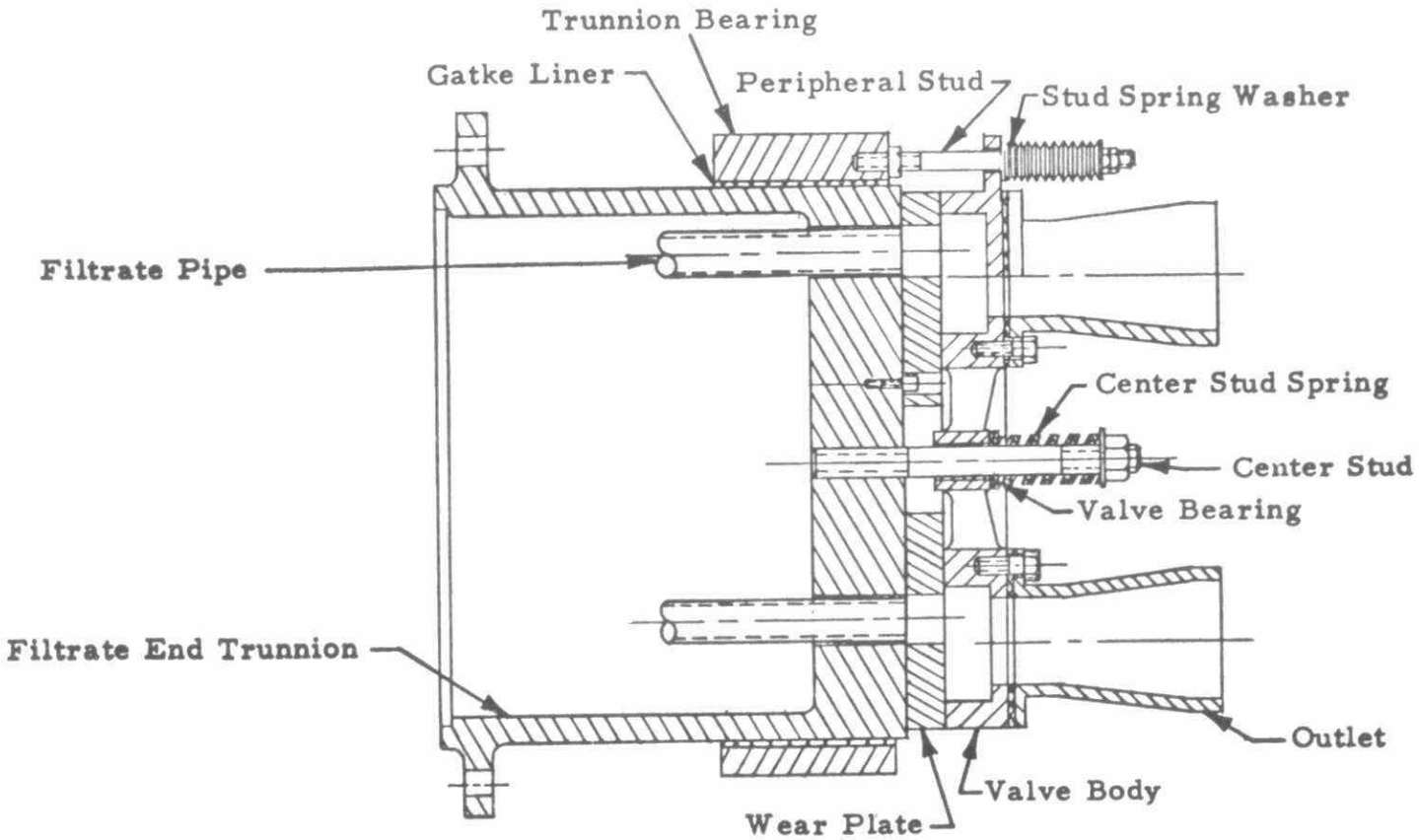


FIGURE 2.

TABLE 1

DESIGN FILTER YIELDS (AFTER CHEMICAL CONDITIONING) WITH STAINLESS STEEL TYPE COILSPRING MEDIA

TYPE OF SLUDGE	DESIGN YIELD (lbs./ft.²/hr.)
Fresh	
Primary	8
Primary and Trickling Filter	7
Primary and Activated	6
Activated (Alone)*	3-5
Digested (Anaerobically)	
Primary	7
Primary and Trickling Filter	6
Primary and Activated	5
Digested (Aerobically)**	
Primary	4
Primary and Activated	3

*Yield depends upon type of process and concentration. Minimum concentration should be 4-5% solids for economical operation.

**Minimum concentration should be 4-5% solids by weight for economical operation.

The vacuum filter is now ready for operation. Sludge is pumped into the filter vat via a conditioning tank where it is gently and thoroughly mixed with the coagulents. When the level reaches the 25% submergence point the drum, vacuum pump and filtrate pump are started.

For initial start-up the valve in the top line from the filter valve is closed. The valve is opened when a filter cake covers the drying section of the filter.

Familiarity with the equipment often leads to abandonment of the above test, even on an intermittent basis. This, we have observed, leads to a general decline in performance and often an increase in chemical costs. There are an increasing number of plants using polyelectrolytes as coagulents and, unfortunately, no simple test as I have just described for ferric chloride and lime has been developed.

We recently carried out the abovementioned Buechner Funnel Test at a plant in Ontario which had reported very high lime requirements. On the day we conducted the tests, the best result was achieved at the Lab using 4-1/2% ferric chloride and 18% lime. The filter was operating at 4% ferric and 30% lime. The filter was left at its original drum speed whilst both chemical feeds were changed. Samples of filter cake showed that the coisture content increased by one percentage point but that the filter cake contained 20% more sludge solids.

This was confirmed by the necessity to increase the speed of the sludge feed pump.

Probably the most consistent operation is that at Sault Ste. Marie where the sludge can be filtered without the aid of chemicals other than those which are present in the plant influent.

Most of the plants using vacuum filters for dewatering sludge are now using some chemical for purposes of nutrient reduction. The use of alum has generally resulted in a lowering of filter yields. Lime has had no noticeable effect and ferric chloride has not affected the yeld but has been observed to reduce the amount of additional ferric chloride required prior to filtration.

The vacuum filters operating in Ontario have, in most cases, been operating for many years. I have no knowledge of the cloth media machines but the Coilfilters, which make up the majority of the installations, have generally required little more than lubrication and, in the case of machines using ferric chloride and lime, acid-washing on a periodic basis. The slow movement of most of the parts of a vacuum filter are conducive to a long and trouble-free life and generally maintenance can be carried out by plant personnel without special skills or equipment.

Checking with our records, we find that spare parts purchases have averaged less than $500.00 per year.

ASPECTS OF INCINERATING CHEMICAL SLUDGES

by

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Wastewater Technology Centre

Environmental Protection Service

Environment Canada

ABSTRACT

This paper reviews basic incineration concepts and common incineration systems. The incineration and chemical recovery program being carried out by the Wastewater Technology Centre (WTC) under Canada-Ontario Agreement funding is described. Preliminary results from the program are presented and discussed.

1 INTRODUCTION

Traditionally, larger municipalities employ incineration for final disposal of their sewage sludges. For example, in Ontario, Metropolitan Toronto, Hamilton and London have incineration facilities. Incineration is capable of destroying essentially all organic matter, provides the maximum volume reduction and is often the cheapest (where access to land disposal sites is remote or limited) method of sludge dis posal. It is a popular misconception that recent energy cost increases will severely affect the economic feasibility of sludge incineration. In fact, recent developments on sludge dewatering, heat recovery and reuse will actually make sludge incineration energy self-sufficient.

The incineration of chemical sludges produced by lime, iron and alum phosphorus removal systems has many potential ramifications. Consequently, research was initiated by the Environmental Protection Service at the Wastewater Technology Centre (WTC) under Canada-Ontario Agreement funding to investigate various aspects of sludge incineration and chemical recovery from phosphorus removal sludges. The objectives of theis paper are to: (i) briefly review incineration practices, (ii) describe the current incineration research program being carried out at the Wastewater Technology Centre, and (iii) present and discuss preliminary results from this program.

2 REVIEW OF INCINERATION AND HEAT TREATMENT CONCEPTS

Detailed review of incineration and heat treatment have been compiled by Balakrishman et al (1970), Owen (1957) and others. Discussion herein will be limited to essential background details.

2.1 Multiple Hearth Incineration

The multiple hearth furnace, with several hundred installations in North America and Europe, has, for the past 30 to 40 years, been the most popular method of incinerating sewage sludges. A flowsheet for a typical multiple hearth furnace is shown in Figure 1. The furnace consists of a refractory-lined steel shell containing a series of horizontal hearths. Sludge alternates from in-feed to out-feed as it is moved downward by rabble arms through the furnace. Combustion gas flow is counter-current to sludge flow. The furnace is divided into three distinct operating zones (e.g. see Figure 7 for temperature profiles). The first "drying" zone (800 to 1200^{o}F), (425 to 650^{o}C) consists of the upper hearths where most of the moisture is driven off. The second "burning" zone (1400 to 1700^{o}F), (760 to 925^{o}C) is where organics are combusted. The third "cooling" zone (400 to 800^{o}F), (200 to 425^{o}C) serves to cool the ash prior to its discharge into the ash quenching facilities or ash hopper. Off-gases from the furnace are generally passed through a wet scrubber before being discharged to the atmosphere. Sludge loadings for multiple hearth furnaces vary from 7 to 12 lb of dry solids/ft^{2}-hr. (34 to 59 kg/m^{2}-hr).

2.2 Fluidized Bed

The fluidized bed furnace (Figure 2) is a cylindrical refractory-lined combustion chamber with a bottom layer of sand supported by a steel grid. Presently there are several dozen fluidized bed sludge incineration installations in the United States. Sand particle sizes range from 0.1 to 0.2 (0.25 to 0.5 cm) inches and bed depth is generally in the order of 3 ft (0.9 m). Combustion air is injected at the base of the bed and maintains it in a fluidized state. Sludge is fed under pressure directly into the bed where drying and some combustion occurs. Additional combustion of gases occurs in the zone above the sand bed. Ash is

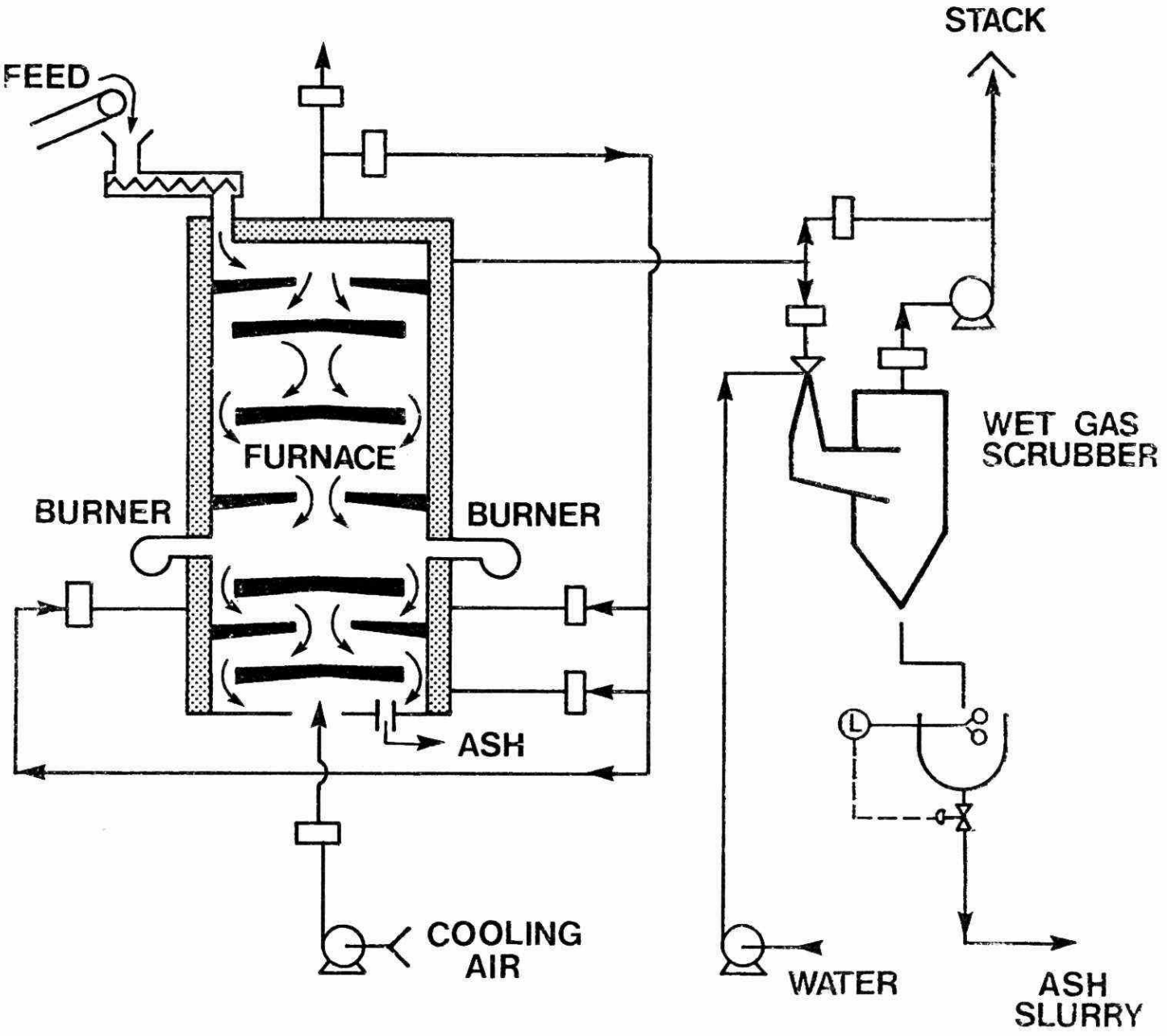

FIGURE 1 FLOWSHEET OF MULTIPLE - HEARTH FURNACE

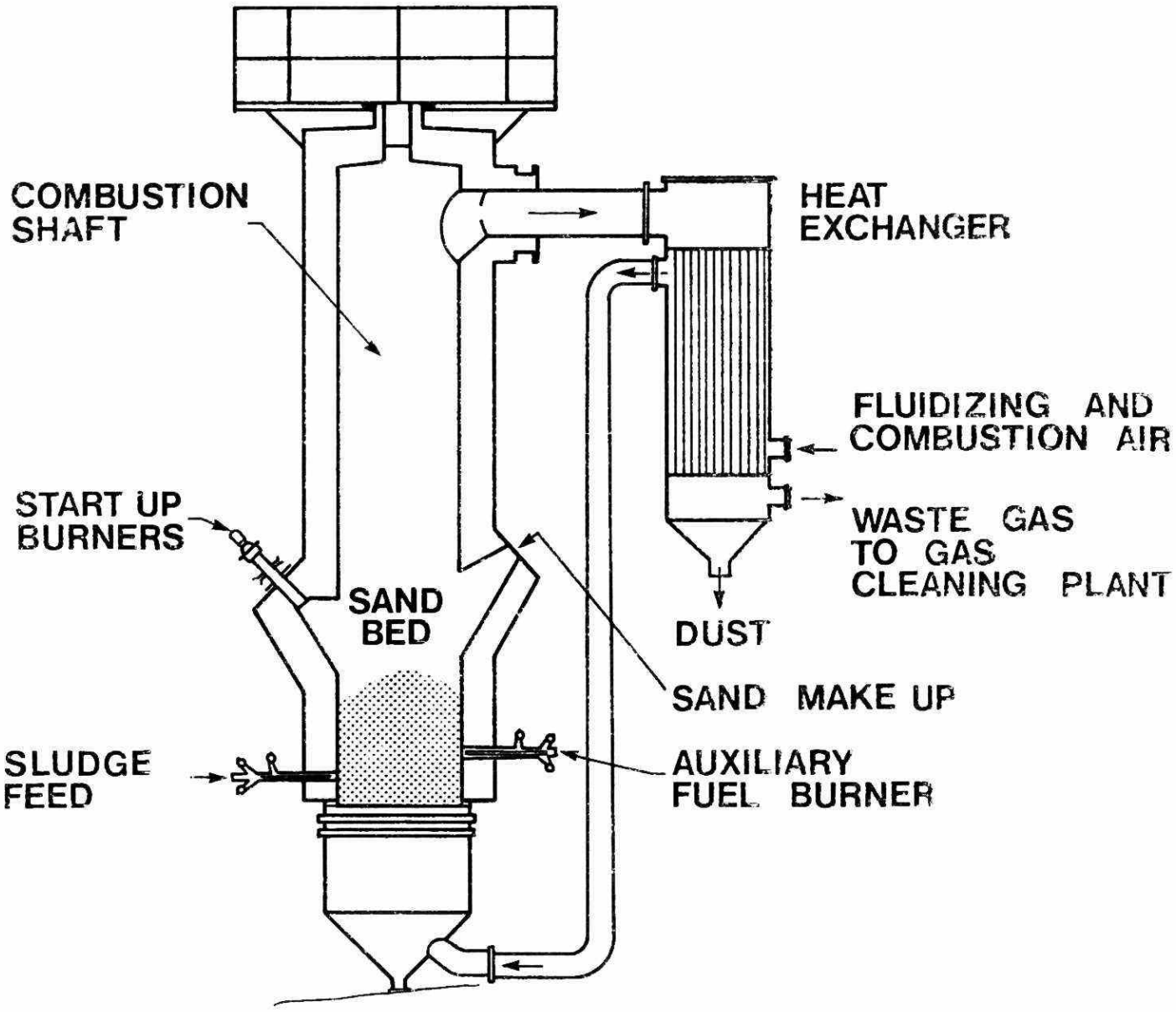

FIGURE 2 FLUIDIZED BED FURNACE

carried out with the off-gas and must be recovered by a cyclone and/or scrubber system. Because of the enormous reservoir of heat in the bed and the rapid distribution of fuel and sludge within the bed, optimum contact beween fuel and oxygen and rapid transfer of heat is ensured. Typical reactor conditions involve temperatures of 1400 to 1500°F (760 to 816°C) and pressures in the order of 2 psi (0.14kg/cm^2).

2.3 Rotary Kiln Furnace

The rotary kiln furnace has not been used extensively for sludge incineration although Harkness et al (1972) describe the potential of the unit for directly handling thickened (undewatered) sludge. The furnace (Figure 3) consists of a refractory-lined slowly rotating drum with a slight horizontal inclination. Sludge is fed into the furnace at the upper end and ash exits at the lower end. It is necessary that the dewatered sludge be adequately disintegrated to provide a large surface area for combustion. Heat losses are high and scaling could occur in rotary furnaces.

2.4 Pretreatment Processes

Sludge dewatering is the most critical pretreatment step for incineration systems (i.e. the greater the solids content of the sludge cake fed to the incinerator the lower the fuel requirements). Sludge dewatering by centrifugation, vacuum filtration, filter press and other methods have been discussed in other papers; therefore, further detail is not provided herein.

A heat treatment method that has experienced considerable popularity, initially in Europe and recently in the United States is the Porteous process (Figure 4). In the Porteous process, thickened sludge is pumped to a reaction vessel through a heat exchanger. In the reaction vessel the sludge is subjected to temperatures of 350-400°F (175-200°C) and pressures of 180-210 psi (12.7-14.8 kg/cm) for a period of approximately 30 minutes. The conditioned sludge (bound water driven-off) is passed back through the heat exchanger giving up its heat to the incoming sludge. The sludge from the decanter vessel can be readily dewatered by conventional methods (e.g. vacuum filtration) to 30 to 40% solids.

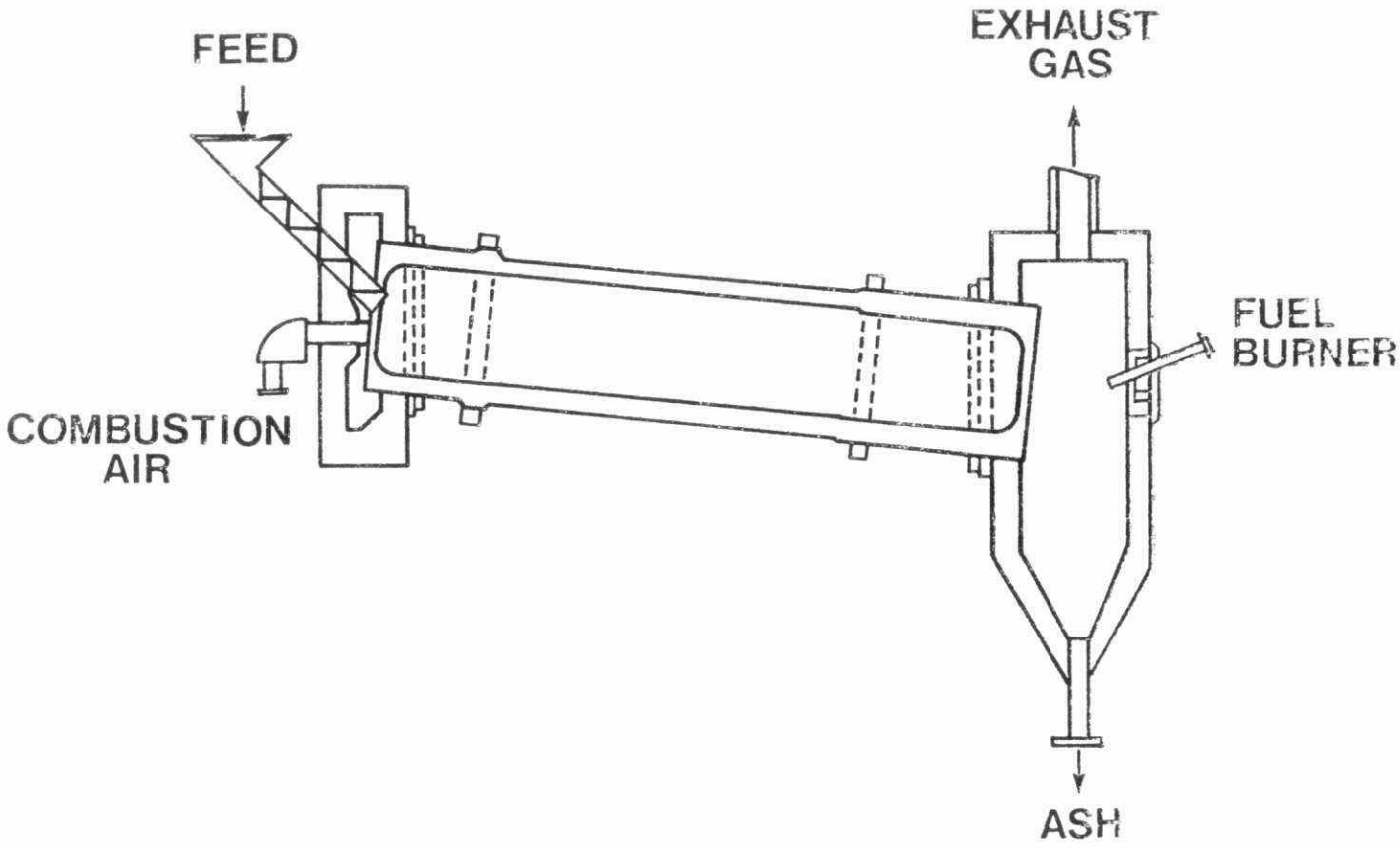

FIGURE 3 ROTARY KILN FURNACE

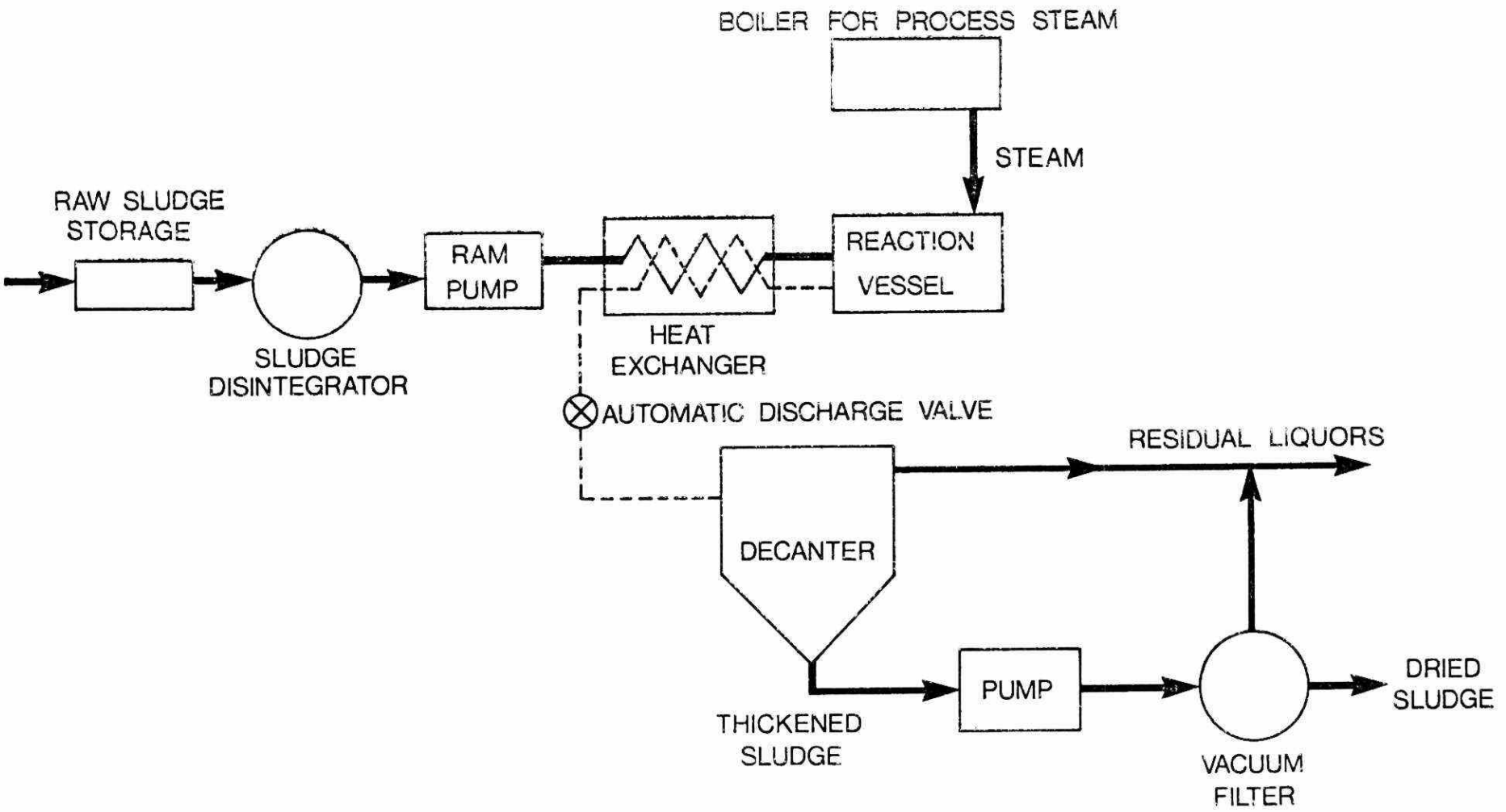

FIG. 4 FLOW DIAGRAM OF THE PORTEOUS PROCESS

2.5 Relative Costs of Incineration and Heat Treatment

A capital cost comparison, Burgess (1968), of multiple hearth, fluidized bed and rotary kiln incineration is shown in Figure 5. Approximate operating costs are summarized in Table 1.

TABLE 1. OPERATING COSTS OF INCINERATION AND HEAT TREATMENT SYSTEMS (BALAKRISHNAN, 1970)

SYSTEM	APPROXIMATE COST[1, 2] ($/TON OF DRY SOLIDS)
Multiple Hearth	$ 6.00 to $10.00
Fluidized Bed	$25,00
Rotary Kiln	No data
Zimpro Wet-Air Oxidation	≃ $15.00
Porteous Process	≃ $ 2.00

[1] Does not include sludge dewatering costs

[2] To convert to cents/kg multiply by 0.11

3 INCINERATION VARIABLES AND CHEMICAL SLUDGES

The critical variables involved in the incineration of sewage sludge include (i) moisture content of the sludge, (ii) calorific value of the sludge, and (iii) the relative proportion of volatile/inert material. The single most important variable is the moisture content of sludge cakes. If a 30 to 40% sludge cake can be produced from the dewatering operation, subsequent incineration is generally assumed to be self-sustaining heat sources and sinks that must be considered in a thermal balance are summarized in Table 2.

Chemical phosphorus removal sludges can have varied effects on incineration processes and these aspects have been dealt with previously by Villiers (1973). Potential problems which may be encountered in the incineration of phosphorus removal sludges are listed in Table 3.

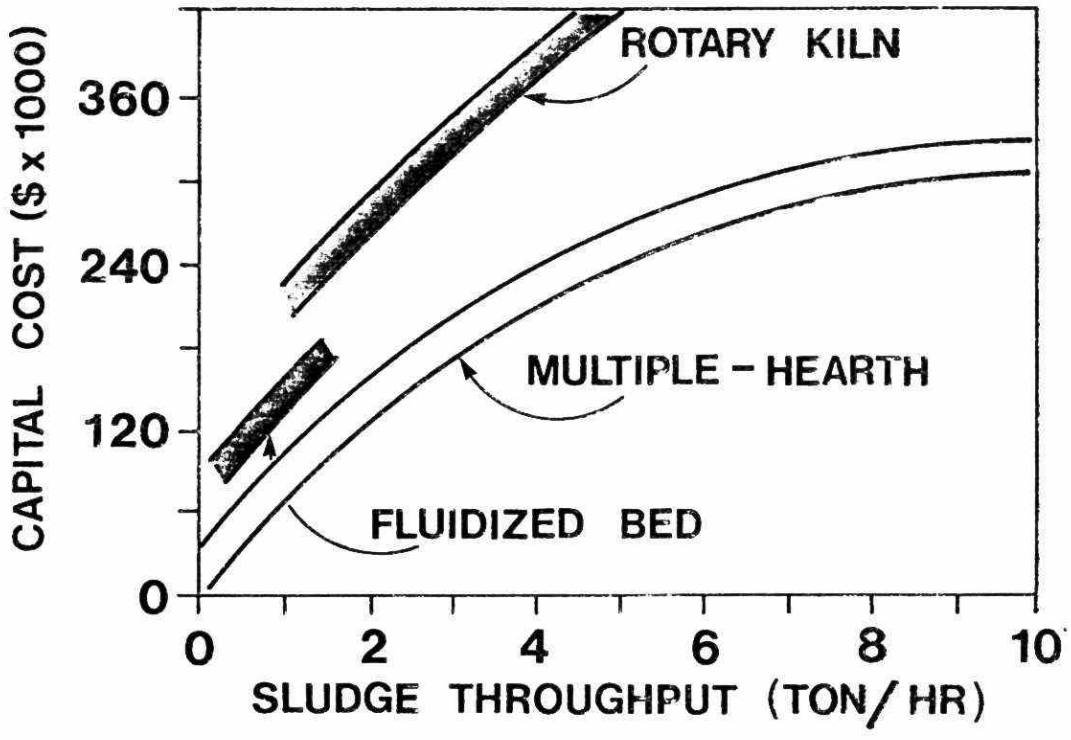

FIGURE 5 RELATIVE CAPITAL COSTS (1970 $) OF INCINERATION ALTERNATIVES (BURGESS ,1968)

TABLE 2. INCINERATION HEAT BALANCE.

HEAT SINKS	HEAT SOURCES
Free Moisture	Volatile Solids
Combustion Gases	
Excess Air	Fuel
Ash	
Radiation	
Shaft Cooling Air	

TABLE 3. POTENTIAL PROBLEMS IN THE INCINERATION OF CHEMICAL SLUDGES.

PROBLEM	SOLUTION
Greater Sludge Volume	Increase Capacity or Run Time
Lower Calorific Value	Increase Fuel
Increased Moisture Content	Improve Dewatering or Increase Fuel
Formation of Clinkers Due to Fe or Al Content	Decrease Incineration Temperature Below Fusion Point
More Inerts	Increase Ash Disposal Capacity

4 THE INCINERATION AND CHEMICAL RECOVERY PROGRAM AT THE WASTEWATER TECHNOLOGY CENTRE

In 1973 the Environmental Protection Service at the Wastewater Technology Centre in Burlington initiated a sludge incineration and precipitant recovery program. Major funding for this continuing project has been provided by the research program of the Canada-Ontario Agreement on Great Lakes Water Quality.

Laboratory and pilot-scale studies are presently in progress to determine (i) the effects of the traditional phosphorus precipitants (lime, iron and alum) on sludge incineration processes, (ii) the feasibility of precipitant recycle (particularly iron and lime) and other by-products

recovery, and (iii) optimum operational combinations of sludge dewatering/incineration processes. In addition, an annotated bibliography of sludge incineration and chemical recovery literature has been compiled.

4.1 Incineration Field Station

The wastewater treatment plant at Canadian Forces Base (CFB) Borden was selected as the site for an incineration field station. The plant at Borden is equipped to operate as a lime, iron salt or alum phosphorus removal system. It treats a flow of approximately 1 mgd by a primary system and four types of sludge (i.e., raw primary, digested primary, lagoon dewatered and drying bed dewatered) can be made available for incineration studies.

A 40 ft by 60 ft pre-engineered building and mobile laboratory trailer facilities have been located on the plant site. Presently housed within the building is an Envirotech-BSP pilot-scale multiple hearth incinerator [30 inch ID, 6 hearth, capable of handling 50 lbs/hr (22.7 kg/hr) of dry solids, complete with wet-scrubber and system instrumentation]. A Bartlett-Snow rotary kiln 11 ft (3.4 m) combustion chamber, [capacity of 1.25 ft^3 (.035 m^3) of sludge/hr] and a Komline Sanderson spray dryer are also located at the field station.

Sludge handling and dewatering facilities include an Eimco thickener and an Eimco [3' (0.9 m) diameter x 1' (0.3 m) face] vacuum filter. Sludge generated by the phosphorus removal system at the treatment plant can be thickened, dewatered and incinerated from either batch or continuous in-put. In addition, these facilities are capable of processing sludges which may, from time to time, be hauled in from other locations.

5 RESULTS FROM THE INCINERATION PROGRAM

Various operational and equipment problems plagued the field station studies in the early stages. Consequently, the first pilot-scale incineration studies did not commence until June 1974. Preliminary results of the incineration program are reviewed in the subsequent sections. Where appropriate, literature results from related studies are reported.

5.1 Calorific Values of Chemical Sludges

The calorific values of several sewage sludges were measured using a Parr oxygen bomb calorimeter. The results of these determinations are presented in Figure 6. Calorific values ranged from a low of 2100 BTU/lb (1167 kcal/kg) for the primary lime sludge at C.F.B. Borden to a high of 8000 BTU/lb (4444 kcal/kg) for a sludge consisting of activated carbon, and primary alum sludge (from a pilot plant at the WTC). In general, digested sludges had lower calorific values than waste activated sludges. The digested chemical sludges from alum and iron phosphorus removal systems had an even lower calorific value than their non-chemical counterparts. A good relationship between sludge volatile solids content and calorific value was observed and the line of best fit and regression equations are shown in Figure 6.

5.2 Incineration of Chemical Sludges

5.2.1 General

At the time this paper was being prepared, results from the pilot-scale multiple hearth experiments were limited. Selected results from the incineration of a primary lime sludge [lime dosage to raw wastewater = 250 mg/l as $Ca(OH)_2$] will be discussed.

Filter cake from the Eimco vacuum filter was conveyed to the incinerator and fed into the number 1 hearth via a screw conveyor. There was evidence of sludge build-up in front of each rabble arm in hearth 1. As the sludge dried, it fell freely to hearth 2. Flame was visible (probably ignition of volatile gases given off by the heated sludge) on the surface of the dried sludge in hearths 2 and 3. By the time the sludge had reached hearths 4 and 5 it had attained a pebble-like structure. The ash removed from hearth 6 by the screw conveyor was finely pulverized and free of lumps. Ash tended to accumulate on the top surfaces of the rabble arms and on the rabble teeth over drop holes. However, there was no evidence of rabble teeth bridging or clinker build-up in the incinerator for the lime sludge. Clinker problems are anticipated for the iron and alum sludges. For example, the City of Hamilton has experienced clinker build-up when trying to incinerate a digested sludge

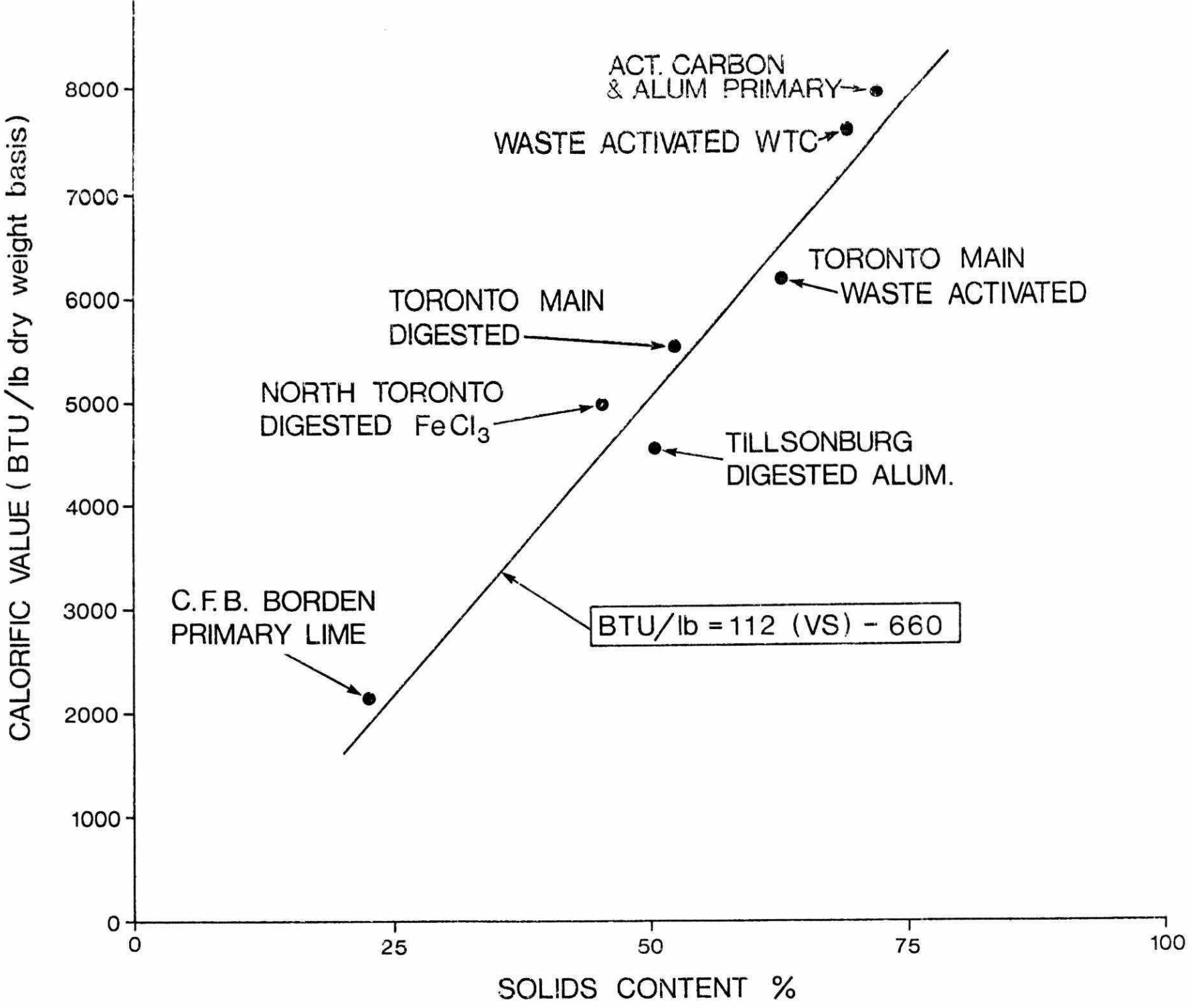

FIG. 6 CALORIFIC VALUE-VOLATILE SOLIDS RELATIONSHIP FOR SELECTED SLUDGES

which is relatively high in iron content (Gross, 1974). Some characteristices of the dewatered lime sludge and the incinerator ash are summarized in Table 4.

TABLE 4. CHARACTERISTICS OF DEWATERED LIME SLUDGE AND THE ASH OBTAINED FROM INCINERATING THE SLUDGE AT 1600°F.

PARAMETER	DEWATERED SLUDGE	INCINERATOR ASH
Total Solids (%)	37.3	-
Total P (%)	1.16	1.65
Ca (%)	17.4	42.8
Al (ppm)	1520	3400
Cu (ppm)	54	210
Fe (ppm)	2425	6060
Zn (ppm)	143	300
Si (%)	1.1	2.1

Feed rate to Incinerator = 39 lb/hr (17.7 kg/hr) of wet solids
Temp. Profile shown in Figure 7

The size of the incinerator has created some problems which must be considered when scaling the pilot plant results to full-scale. First, the small 15" (38.1 cm) radius of each hearth permitted some short circuiting of sludge and ash. As a result, some sludge pebbles exited the incinerator with cores containing partially burned material. Secondly, the small volume of the incinerator does not permit exact control of the furnace temperature profile from top to bottom. Figure 7 illustrates this point for temperature profiles of 1500°F (815°C) and 1600°F (871°C). Heat generated in the lower hearth maintains the temperatures in hearths 1 and 2, 100 to 200°F (38 to 93°C) higher than desired. Thirdly, the small diameter of the unit and the short drop distance between the hearths brings the sludge and ash in close contact with the burner flames. This in turn results in more even burning across the hearth than would be achieved in a full-scale unit. Comparison studies of the pilot and full-scale incineration of Hamilton sludge are planned later in the program.

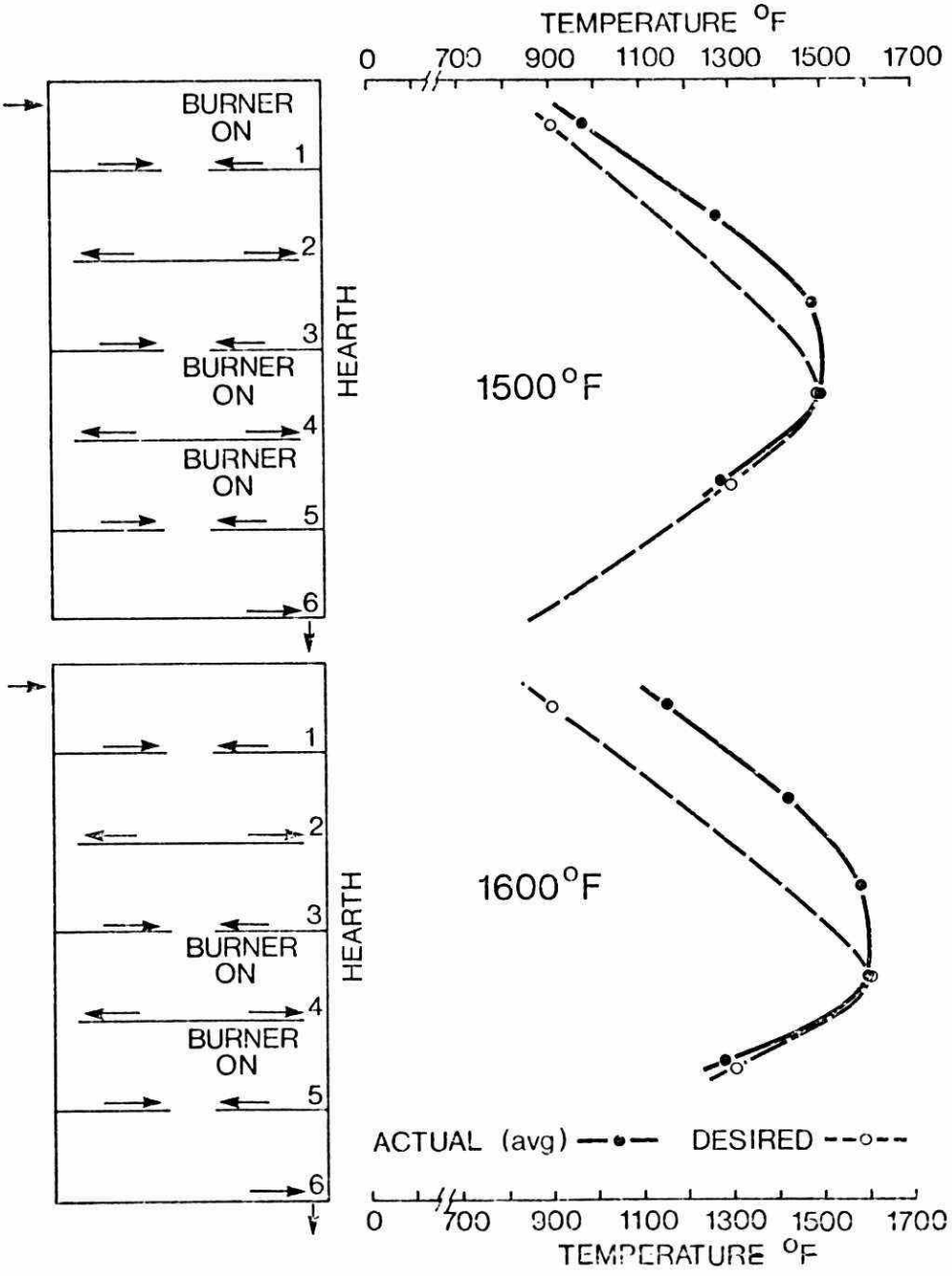

FIGURE 7 TEMPERATURE PROFILES IN THE PILOT MULTIPLE HEARTH INCINERATER

5.2.2 Characteristics of Scrubber Water

Considerable particulate and gaseous materials produced during sludge incineration are ultimately removed in a wet-gas scrubber. The characteristics of the scrubber water produced during incineration must be considered as this water must be disposed of or treated in an acceptable manner. Several investigators have reported scrubber water characteristics. Data compiled by Tench et al (1972) for the Sheffield, England sludge incineration plant are summarized in Table 5. Data collected from the WTC incineration experiments are included for comparison purposes.

It is evident from Table 5 that scrubber waters can have significant BOD, nutrient and metal concentrations. However, the proportion of scrubber water/to total plant flow sill dictate how readily the scrubber water can be recycled back to the head of the treatment plant.

TABLE 5. ANALYSES OF SCRUBBER EFFLUENTS.

PARAMETER	RANGE[1]	AVERAGE[1]	WTC STUDY
pH	8.3 to 11.8	8.8	≃7
SS	600[2] to 7690	1760	≃200
COD	110 to 2600	520	-
BOD_5	30 to 80	-	17 (TOC)
NH_3-N	29 to 244	92	7
Cd	N.D.[3] to 42	4	-
Cr	N.D. to 250	24	-
Cu	N.D. to 57	7	0.06
Ni	N.D. to 23	5	-
Zn	N.D. to 159	29	0.14

[1] Data from Tench et al (1972)

[2] All values in mg/l except pH

[3] N.D. = not detectable

Tench et al (1972) estimated that the recycle of scrubber water increased the COD of the influent wastewater by a mere 1.4%. It is common practice at many incinerator installations to dispose of the slurried ash and scrubber water into an ash lagoon. In these cases, the pollutant content of the scrubber water may also be of concern.

5.2.3 Stack Emissions

Detailed material balances over the multiple hearth incinerator are planned at a later stage in the WTC incineration program. These balances will include measurement of carbon, nitrogen, phosphorus and metal loadings in the sludge, ash, scrubber water and stack gas. An EPA task force on incineration has summarized stack emmission data from several sludge incinerations. Some of these data are presented in Table 6. It is evident that SO_2 and NO_x emmissions are relatively high. However, with an efficiently operated scrubber, particulate emissions can be maintained at a low level.

TABLE 6. STACK EMISSIONS FROM SLUDGE INCINERATORS (EPA TASK FORCE 1972).

PARAMETER	FLUIDIZED BED BARSTOW, CAL.	MULTIPLE HEARTH MONTEREY, CAL.
Stack Flow (SCFM)[1]	1190	3310
% Excess Air	38.7	469.2
SO_2 Emission (ppm)	10.7	2.2
No_x Emission (ppm)	161.6	35.4
Particulates (gr/SCFD)[2]	0.067	0.037
Sludge Feed	510	$\simeq$675
Scrubber Type	Perforated Plate	Perforated Plate

[1] To convert to m^3/min multiply by 0.0275

[2] To convert to g/m^3-day multiply by 2.19

[3] To convert to kg/hr multiply by 0.453

6 PRECIPITANT RECOVERY

6.1 Lime Recovery

It has been demonstrated in the Lake Tahoe project (Culp et al, 1971) that lime can be recovered from tertiary ($CaCO_3$ recovered by recarbonation of high pH effluent) lime sludges and recycled for phosphorus removal. Fresh lime makeup in the order to 20-25% is required to prevent a build-up of inert material. The recalcined lime is as reactive as fresh lime and equally effective in phosphorus removal.

Lime recovery from primary sludges is inherently more difficult, although recent work by Parker et al (1973) has shown that selective centrifugation is capable of wet classification and separation of $CaCO_3$ from the main sludge mass. The $CaCO_3$ can be recalcined and recycled. Sludge classification and lime recovery will be conducted as a later phase of the WTC program.

6.2 Iron Recovery

Unitl recently little serious consideration has been given to the recovery and recycle of iron salt precipitants. Under Canada-Ontario Agreement funding, Scott (1973), Scott and Horlings (1974) and Cambrian Processes Ltd. (1974) have studied various aspects of iron and by-product recovery. The Scott and Horlings (1974) results dealing with metal recovery from digested sludges are included in the seminar proceedings. Cambrian Processes Ltd. (1974) have estimated that approximately $73 worth of metals and phosphoric acid could be recovered from each ton of Ashbridges Bay (Toronto) incinerator ash. A breakdown of the recoverable materials is presented in Table 7. Their proposed recovery system precluded iron recovery and recycle.

TABLE 7. POTENTIAL RECOVERY OF MATERIALS FROM ASHBRIDGES BAY INCINERATOR ASH (CAMBRIAN PROCESSES, 1974).

COMPONENT	RECOVERABLE FORM	RECOVERABLE AMOUNT (lb/ton)	VALUE ($/ton ASH)
Cr	$Cr(OH)_3$	36.8	19.00
Cu	CuS	11.4	3.00
Ni	NiS	1.6	0.80
Pb	PbS	5.4	0.30
Zn	ZnS	33.4	3.40
P	H_3PO_4	356.0	46.50
		TOTAL -----	$73.00

Preliminary work at the WTC indicates that iron recovery from high iron content (e.g. Hamilton ash and iron phosphorus removal system) incinerator ashes is feasible. As illustrated in Figure 8 more than 90% of the leachable iron in the Hamilton incinerator ash can be solubilized with 7.2 N H_2SO_4 in two hours contact at 90°C. Of course the resultant solution will contain other heavy metal components which must be removed, recovered, or at least reduced before the iron salt would be recycled as a phosphorus precipitant. The availability of the iron and other metals in the ash will be affectd by incineration conditions. The incineration temperature - metal recovery aspects are currently being investigated at the WTC.

7 SUMMARY

The sludge reduction program at the Wastewater Technology Centre is presently investigating many facets of sludge incineration and chemical recovery. Preliminary findings from these continuing studies indicate that:

(i) lime, iron salt and alum phosphorus removal precipitants contribute to sludge inert material and thereby reduce the calorific values of primary, digested and waste activated sludges;

(ii) multiple-hearth incineration of lime sludges presents no unexpected difficulty, however, clinker problems are anticipated with high temperature (>1500°F), (815°C) incineration of iron and slum sludges;

(iii) The recovery of iron and other heavy metals from incinerator ashes is feasible and the recovered iron salt could eventually be recycled as a phosphorus removal precipitant.

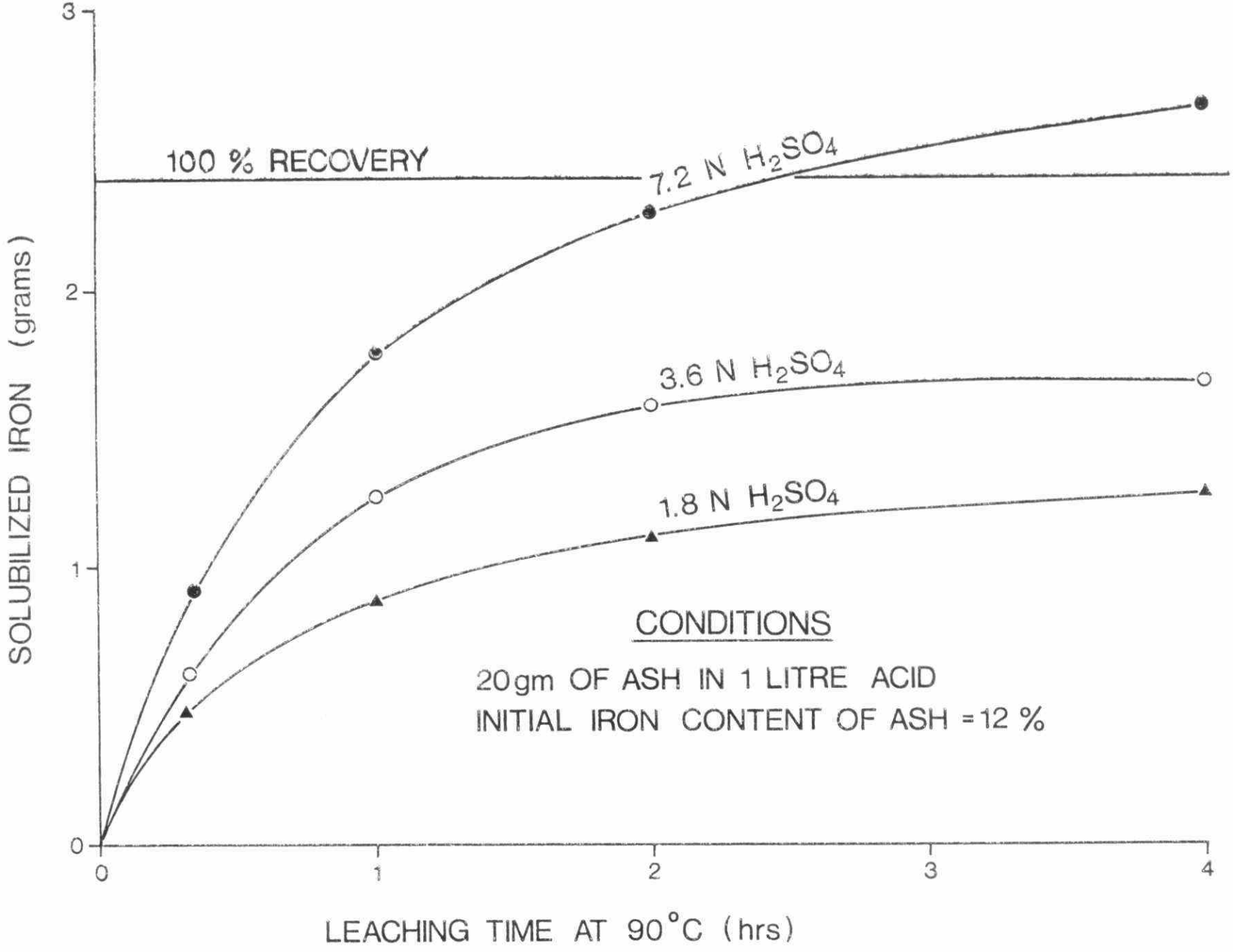

FIG. 8 IRON RECOVERY BY SULFURIC ACID FROM HAMILTON SLUDGE INCINERATOR ASH

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REMOVAL OF PHOSPHATES AND METALS FROM SEWAGE SLUDGES

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ABSTRACT

Most of the metals and phosphorus in either unconditioned or conditioned final anaerobically digested sludges can be readily extracted by acid. The acid extract can be neutralized under controlled conditions of pH to yield a solid product low in organic material containing mostly iron and aluminum phosphates. By proper control of pH, it is possible to produce two solid products, one containing most of the iron and aluminum and one containing most of the heavy metals.

This technique of metal removal appears to be generally applicable to digested sludges. The crude metal-phosphate products can be treated by conventional means for recovery or recycle. From 80-90% of the iron, aluminum, zinc and phosphate entering a treatment plant from all sources can be recovered in this way. The amounts of minor heavy metals removed from the sludge are more variable and depends on the acid used and the source of sludge, although high removal efficiency is possible by adjusting extraction conditions.

1. INTRODUCTION

With the advent of chemical treatment for the removal of phosphates in wastewater treatment plants, the sludges produced from these plants will now contain the bulk of the phosphate in the original influent streams. In addition to its phosphate content, the sludge will also contain most of the metallic cations entering in the influent stream, as well as the metallic cations such as iron or aluminum which may have been added as treating chemicals to effect phosphate removal, or as coagulants. Whether the sludges are mixed sludges, activated sludges, or primarily anaerobically digested sludges, they will all contain the

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bulk of the metals and phosphorus that originally entered the treatment plant.

The role of metals in the sludges, particularly the heavy toxic metals such as copper, chromium and zinc is not yet completely appreciated. In the concentrations usually found in treatment plant liquids there is no apparent adverse affect on biological activity in the treatment plant processes themselves. However, the metals become concentrated to a considerable degree in the sludge and some of them frequently reach appreciable levels (e.g. 5% by weight of dry solids or more). The case of anaerobically digested sludge is particularly interesting because of the reduction in sludge volume during digestion, and the correspondingly increased metal content. It is questionable whether sludge from anaerobic digestion can be used repeatedly for agricultural purposes on a given piece of land. There is also some evidence that leachates and run-off waters from sludge land disposal sites may contain undesirably high quantities of dissolved heavy metals and of phosphates. Certainly, the thickener underflow from an anaerobic digester prior to dewatering or disposal usually contains amounts of copper and chromium which if they became soluble would appear to far exceed recommended maximum safe limits.

If it were possible to remove most of the heavy metal content from the sludge this might be desirable, particularly in cases where the sludges are to be used for agricultural purposes or where there is a more than a normal contamination with heavy metal impurities. In addition, there is the possibility that if iron or aluminum has been added for phosphates removal, these metals could be recovered and recycled within the treatment plant. The high phosphate content of sludges is sometimes also undesirable, for some of this material can leach out from sludge disposal sites, particularly if the sludge is fairly alkaline or fairly acid, and ground waters may feed the phosphate pollution back into the watershed system.

There is not yet, apparently, any process which offers workable technology for removing metals and phosphates from underflow sludges, of filter cake sludges. The principal objective of this study was to investigate means of carrying out a separation of the metals and phosphates from a typical sludge, and as a secondary consideration, to determine

whether a ready means was available for economically purifying and recycling some of these materials.

2. NATURE OF THE PROBLEM

There are many kinds of sludges produced from waste treatment plants, and a wide variation in sludge compositions depending on the waste source and the type of process. However, from the viewpoint of their major metals content, these sludges can be characterized roughly according to whether iron or aluminum have been used for phosphate precipitation, and whether or not the sludge has been produced with an anaerobic digestion step. This latter distinction is of some importance because the sludge volume is considerably less when anaerobic digestion is used, with correspondingly higher contents of metals and phosphates. In addition, anaerobic sludges may have some metals, e.g. iron, in lower valence states, with a corresponding difference in behaviour from oxidized sludges.

Because of the higher metal concentrations an anaerobic sludge was selected for this study. Inasmuch as iron is likely to be a major chemical used for phosphate removal, a plany employing ferric iron addition for this purpose was also desired. Both of these requirements were met by the North Toronto Treatment Plant of the Metropolitan Toronto Water Pollution Control Agency. This plant has employed phosphate removal using ferric chloride addition for nearly three years. It produces a sludge which is the product of primary and secondary treatment combined with anaerobic digestion. The sludge underflow from the final thickeners is conditioned by the addition of ferric chloride and lime prior to vacuum filtration. Therefore sludge was available both as an underflow without conditioning chemicals added and as filter cake which contained conditioning chemicals. All work reported in this study was done using material from this plant.

Recent literature does not reveal any reports of investigations undertaken for the same objectives as those set out for this study. Presumable, the removal of metals and phosphate from treatment plant sludges represents a stage of tertiary treatment which is not yet being

seriously considered. Most tertiary treatment is devoted to further purification of effluents. Less attention has been paid to reducing problems of sludge disposal by removing from the sludge some of the possibly undesirable chemical constitutents. Because so little attention seems to have been given to this problem it was necessary to investigate nearly every aspect of behaviour in exploring techniques of extraction and recovery of chemicals from sludges. Also as a consequence of this lack of previous work, a great many alternatives are possible.

A typical anaerobic sludge produced primarily from domestic sewage, and in which iron has been used for phosphate removal, contains about 7% iron, about 6% calcium and 11 - 12% of phosphorus (expressed as orthophosphate*) based on dry sludge weight. After conditioning for filtration the sludge on a dry weight basis can contain 8 - 9% or more of iron, about 11 - 12% calcium and about 12% orthophosphate. In addition to these major elements, the sludge also contains small but significant amounts of aluminum, zinc and copper, and minor amounts of many other metals.

In order to separate some of these components, and particularly the phosphate, from the bulk of the solids, one can solubilize orthophosphate either into strongly alkaline or strongly acidic solutions. In the former case the orthophosphate and much of the aluminum and zinc would go into solution, but very little of any other metals. However, it might also be expected that a very substantial proportion of the organic matter might become soluble or colloidal in form in strongly alkaline solutions. On the other hand, in an acid solution not only the orthophosphate would go into solution, but essentially all the metallic cations. However, only the lower molecular weight organic compounds might be expected to go into solution and might represent a relatively small percentage of the organic matter. For this reason, acid extraction was selected as the first step in treating a sludge.

Having obtained from a sludge an acid extract in which most of the metallic cations are present together with many soluble organic materials, two possibilities are now evident. Either this extract can

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* Throughout this report phosphorus is assumed to be present in the sludge as the appropriate form of orthophosphate. It is acknowledged that this assumption is not always entirely valid.

be treated in order to remove desired components, for example, particular metallic cations or particular anions by chemical means such as precipitation as insoluble salts, or the extract can be subjected to nonchemical steps such as solvent extraction, crystallization, etc. If solvent extraction or some other physical separation is used, then the organic impurities in the extract are likely to cause problems and contamination. However, the possibility also exists that chemical methods can be used to further purify the solution, particularly by removing the bulk of the organic materials in the extract. Solvent extraction, etc., might then be applied to the product of this further chemical purification step. Given the very low economic value of the principal components, that is iron (or aluminum) and phosphate, it is apparent that in any recovery process the minimum consumption of reagents and the minimum number of processing steps are necessary if the costs of removal of these materials from sludges are not to be excessive.

It can be seen that there are a large number of alternate choices in techniques that might be used, in the order in which these recovery steps may be undertaken, and in the choice of reagents to be used for various purposes. In addition, if the iron is recovered and recycled, it must not involve recycling also of the major part of any of the harmful constituents, for example, copper, or a resultant build-up in the heavy metal content in the treatment plant streams could result.

One successful technique for separating metals and phosphates from sewage sludges prior to ultimate disposal is described in the following. Other possibilities also exist, and much more investigation of these other potentially useful approaches is needed.

3. EXPERIMENTAL WORK AND RESULTS

3.1 Extraction of Conditioned Filter Cake

The filter cake sample used in all tests was taken across the length of the doctor knife of the rotary vacuum filter used for the final sludge dewatering step, after addition of lime and ferric chloride to feed to the filter (filter feed was the underflow from the thickeners

following anaerobic digestion). Phosphorus removal was accomplished by addition of 7.2 mg/l of Fe as $FeCl_3$. In addition, about 2.6 mg/l of Fe as $FeCl_3$ was added prior to dewatering in the filter feed tank together with about 24 mg/l of 90% lime. Plant records indicated that the filter cake contained 17.2% dry solids.

The dewatered sludge was analyzed according to standard methods. In order to establish reliable initial values for metals and phosphorus content, sludge digestion and subsequent analysis was carried out by three methods, nitric acid - sulphuric acid digestion, nitric acid - perchloric acid digestion, and hydrochloric acid digestion.

The only meaningful total carbon and COD values were obtained from the HCL digestion, since the oxidizing acids destroyed organic material. Calcium values cannot be obtained when sulphuric acid is used for digestion because of the calcium sulphate precipitation.

The average results of analyses are given in Table I. As expected, iron, calcium, aluminum, and phosphorus are the major inorganic constituents. Other metals only total about 4% of the solids, with zinc and copper being present in the largest amounts. Metal analyses were all carried out by atomic adsorption, while phosphorus analysis was done by the heteropoly blue method.

The degree of extraction of various constituents by treatment with hydrochloric or sulphuric acids was measured by using a standard sample amount equivalent to 20 gm of dry sludge solids in 1000 ml of reaction mixture. The mixture was added, acid was agitated in an open reaction flask held in a constant temperature bath. Amounts of added acid were calculated on the basis of the stoichiometric requirement of calcium, iron, aluminum and zinc ions in the sludge. However, other cations, both inorganic and organic, are also present, some in unknown amounts, and have not been included. Therefore, amounts of "excess" acid given are somewhat too large, e.g. what is reported as 15% excess is probably approximately the stoichiometric equivalent. Other possible acid usage parameters, such as titrable acid, for example, were not found to be satisfactory because of the strongly buffering nature of the solutions.

TABLE I

ANALYSES OF DE-WATERED SLUDGE

MOISTURE = 79.15%

Component		Concentration, mg/gm. dry sludge		
		A	B	C
Total Iron	(Fe)	85.5	88.0	87.5
Phosphorus	(P)	39	40	38.5
Calcium	(Ca)	-	116	120
Aluminum	(Al)	-	-	11.8
Zinc	(Zn)	1.94	2.06	1.88
Copper	(Cu)	0.91	1.02	0.98
Chromium	(Cr)	0.39	0.40	0.41
Manganese	(Mn)	0.30	0.34	0.34
Nickel	(Ni)	-	Trace	-
Lead	(Pb)	-	Trace	-
Total Carbon in Extract		30.1	23.8	55.0
C O D		9.73	3.98	67.3
Residue after Digestion		318.6	111.6	229.9

A - Nitric acid - sulphuric acid digestion

B - Nitric acid - perchloric acid digestion

C - Hydrochloric acid digestion

With an 80% moisture content, one disadvantage in extracting the wet sludge would be the resulting dilute solutions obatined. One way to avoid this result is to pre-dry the sludge. Therefore, sludge was dried at 100°C, the dried sludge was ground to -16 mesh, and 20 gram samples of this material were also tested.

The amount and rate of extraction of total iron and of phosphorus were used as indicators of the extraction efficiency. Results are shown in Figures 1 and 2 for four extraction tests, all at 25.5°C. Dried and "as is" sludge were used in two tests, both with 100% excess HCL, which showed very clearly the detrimental effect of a pre-drying step on the ease of extraction of both iron and phosphates. Even after three hours only 70% extraction had been achieved from the pre-dried solids, whereas the undried sludge gave a 95% yield at the same conditions in three minutes. Other tests at other conditions confirmed the loss of easy solubility resulting from sludge drying. Tests were also carried out using 100% excess sulphuric acid and a 15% excess amount of hydrochloric acid. Results in Figures 1 and 2 show that hydrochloric and sluphuric acid perform equally well in dissolving iron and phosphates, but that some excess over the approximate stoichiometric equivalent is required.

On the basis of these preliminary tests, only sulphuric acid was used in further work. The use of sulphuric acid was clearly advantageous because of its low cost, because of its ability to remove much of the calcium as $CaSO_4$ precipitate, and because of the improved filterability of the leach mixture when sulphuric acid was used (possibly due to the large amount of granular $CaSO_4$ formed).

Additional tests and observations indicated that sludges leached for long times at high acid excess showed very poor filterability. Reduction of leach time and reduction of acid strength both improved filterability. However, about 50% excess acid was required to obtain high extractions of iron or phosphorus in short times. Hot acid extraction of sludge did not improve filterability, but if the sludge was extracted at room temperature, then heated to boiling and filtered hot, a dramatic improvement in filterability resulted. Filterability was measured according to the methods described in Manual No. 20, "Sludge Dewatering" of the Water Pollution Control Federation, (1969).

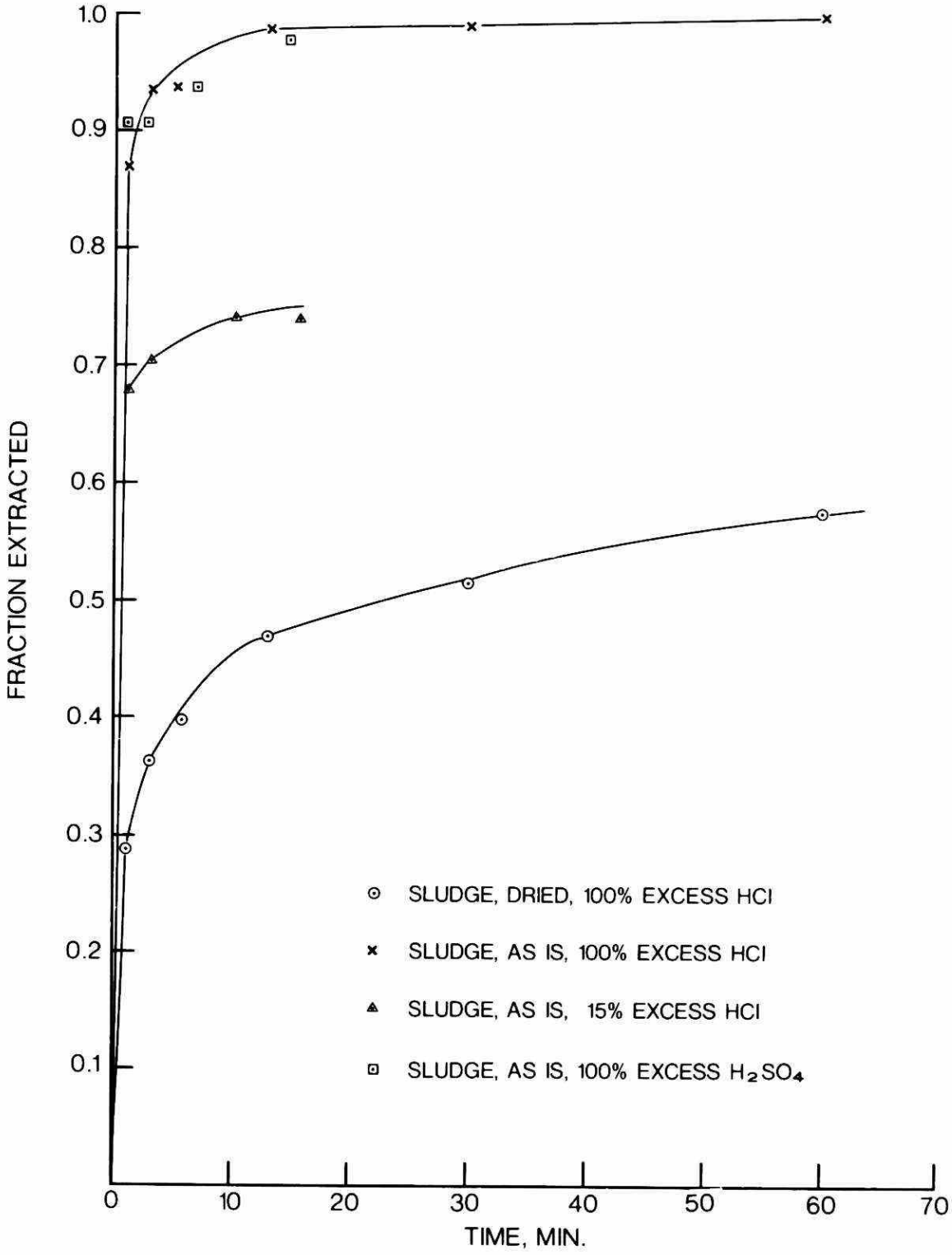

Figure 1. Preliminary Tests of Iron Extraction Rates; Leaching Conditions-Sample Weight Equivalent To 20 Gms Dry Solids in 1000 Mls. Slurry, 25.5° C.

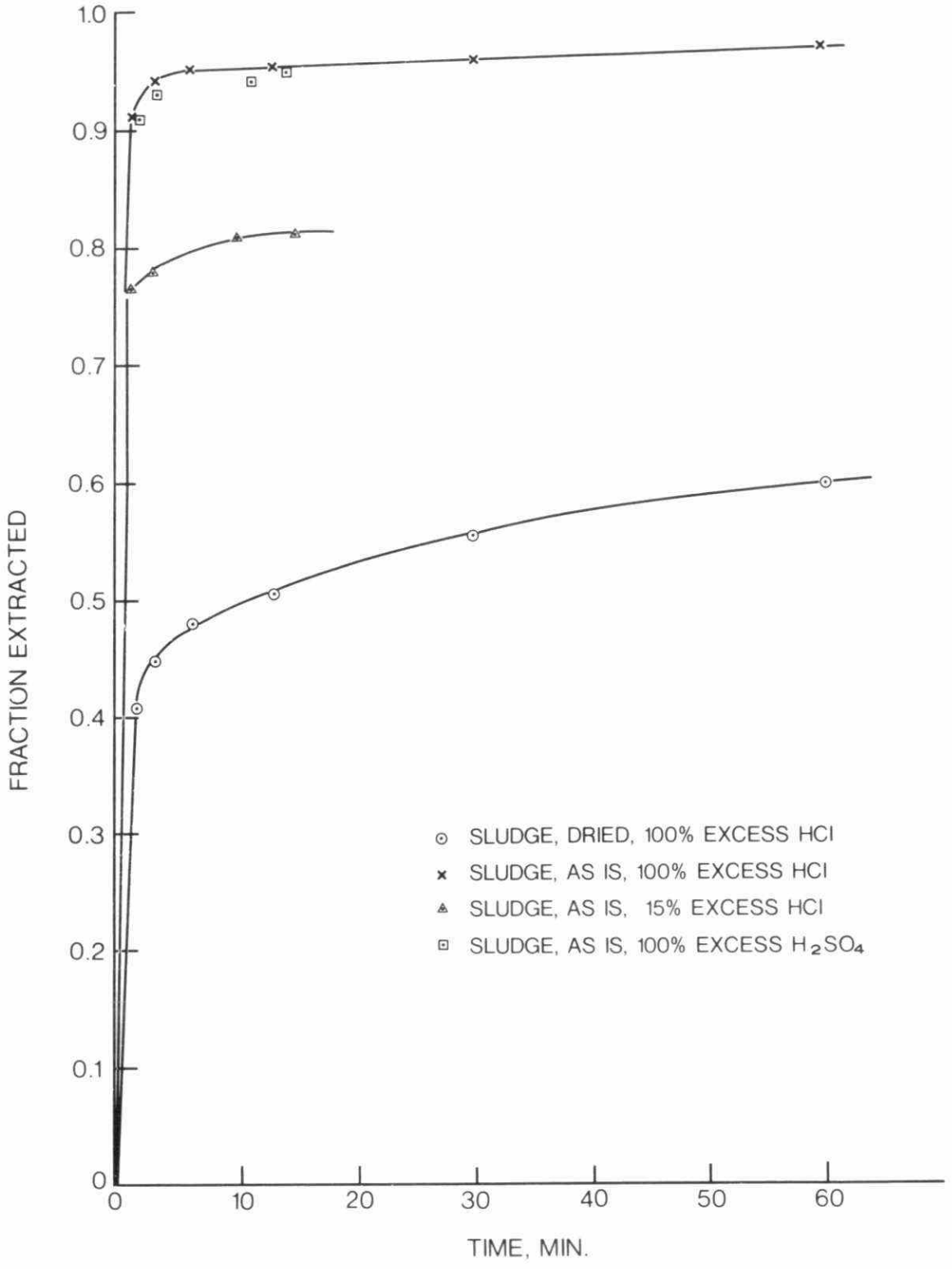

Figure 2. Preliminary Tests of Phosphate Extraction Rates; Leaching Conditions- Sample Weight Equivalent to 20 Gms Dry Solids in 1000 Mls Slurry, 25.5°C.

The sludge filterability index is the ratio of the resistance to filtration compared to the original untreated sludge.

Results of tests at one set of conditions as shown in Figure 3 illustrate the type of results obtained. For this case, the region of 50% to 60% excess acid represents optimal conditions, in that the filterability index is a minimum (about 0.33) and the maximum extraction of iron and phosphorus possible at these conditions has been nearly attained.

3.2 Preparation of Leach Liquor

Because the original sludge filter cake contained only about 19% solids, this placed a limit on the concentration of extract obtainable. The maximum solids content of the reaction mixture could, in fact only be about 11% if a reasonably fluid reaction mixture was to be obtained.

Concentrated sulphuric acid was added in 47.2% excess to filter cake with sufficient additional water to give a final slurry of 11% solids content. After extraction for 15 minutes, the reaction mixture was heated to boiling, and then immediately filtered. After filtering, the residue from the extraction step retained a substantial fraction of the leach liquor and a careful displacement washing of the filter cake was carried out.

The degree of extraction achieved was determined by taking a known volume of concentrated leach liquor, filtering off the leached boiled sludge, washing the cake, and then re-slurrying and filtering the cake twice. The original filtrate and the washings were combined and then analyzed. Results are given in Table II.

As expected, essentially all metals having soluble sulphates are extracted nearly 100% by this procedure. The leach liquor is moderately dilute, and contains as soluble orthophosphate about 77 - 80% of the total phosphorus in the original influent to the treatment plant. The iron in the leach liquor is about one half in the ferrous form, a result of the anaerobic treatment step in the plant.

3.3 Extraction Tests on Unconditioned Sludge

A sample of the underflow from the final clarifiers was obtained from a sampling valve in the filter feed line ahead of the feed conditioning tank. The filterability of this unconditioned material was considerably poorer than that of the conditioned sludge. The sludge

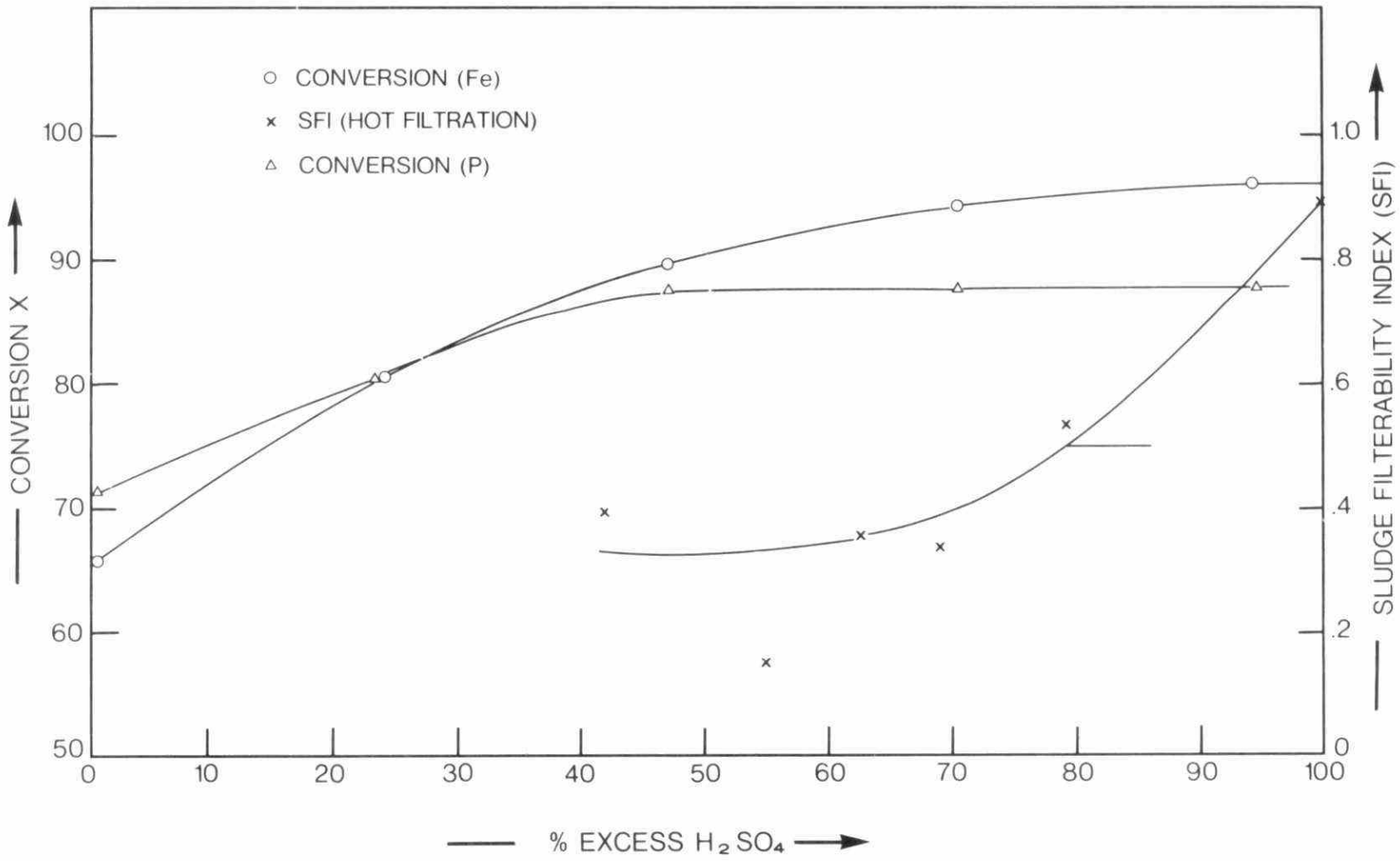

Figure 3. Optimization of Excess Acid - H_2SO_4 With Sludge Sample Equivalent to 20 Gms Dry Solids, 1000 Mls - Reaction Mixture, 25.5° C; Leaching Time 15 Minutes + 15 Minutes Heating.

TABLE II

EXTRACTION YIELDS AND EXTRACT COMPOSITION

CONDITIONED FILTER CAKE

	% Extracted from Cake	Concentrated Extract Liquor, Gms/litre
Iron	100	14.0
Phosphorus	84.7	4.7
Calcium	24.9	4.3
Zinc	100	0.27
Copper	99	0.14

filterability index, that is, the ratio of specific filtration resistance of the unconditioned material to that of the conditioned material, was 75.

The detailed analysis of the metallic components of the sludge is given in Table III. The pH of this sludge was rather high at 9.1, and it contained a significant amount of calcium, although only about one-half of that in the conditioned sludge.

The results given in Table III were obtained by using hot digestion for two hours in concentrated hydrchloric acid. Apart from the decrease in calcium content of the sludge, the other noteworthy difference between this material and the conditioned sludge is the fact that all iron in the unconditioned sludge is in the ferrous form.

On the basis of the knowledge obtained from the extraction tests with the conditioned sludge, the unconditioned sludge was leached at only one set of conditions, that is, with 25% excess acid where the acid equivalent was calculated on the basis of the iron, zinc, calcium and aluminum contents. The sludge was extracted at its process concentration of 7% solids content by the addition of concentrated sulphuric acid, using the same method as described earlier. The solubilization of phosphate and iron proceeded very rapidly at room temperature and reached maximum yield within fifteeen minutes. The extract solution was tested for filterability after bringing the extract solution to the boiling point and filtering hot. Filterability was improved significantly by this procedure over that of the original unconditioned sludge, but still not to the level of a properly conditioned sludge.

In Table IV is shown the recovery of phosphate and iron in the extraction of the unconditioned sludge solids. It will be noted that the heating of the solution to boiling caused a small increase in yield, however, extraction was 85 to 90% even in the cold, and over 90% after heating.

Composition of the leach liquor obtained, given in Table V, shows some interesting differences from that reported in Table II. No copper could be detected in the extract, whereas the extract from the filter cake contained all of the original copper. One can only speculate that in the former the copper was present primarily in the cuprous form, and since cuprous salt are insoluble or unstable in acid sulphate solu-

TABLE III

ANALYSIS OF DIGESTER UNDERFLOW

Moisture 93.0%		
% dry solids 7.0%		
pH 9.1		
Volatile Solids 3.23%		
		mg./gm. dry sludge
Iron	Fe^{++}	75.0
	Fe^{+++}	0.0
Aluminum	Al	7.8
Calcium	Ca	64.2
Zinc	Zn	2.87
Copper	Cu	1.23
Manganese	Mn	0.33
Chromium	Cr	0.79
Phosphorus	P	37.4

TABLE IV

ACID EXTRACTION OF DIGESTER UNDERFLOW

	Extraction Conditions	Fe		P	
		gms/litre	% extracted	gms/litre	% extracted
1.	Hot boiling conc. HCl for 2 hours	5.40	100	2.67	100
2.	25°C, 25% excess H_2SO_4 15 min. extraction time, no heating	5.03	93.1	2.35	88.0
3.	25°C, 25% excess H_2SO_4 15 min. extraction time, followed by 15 mins. heating to boiling	5.35	99.1	2.42	90.6

TABLE V

ANALYSIS OF EXTRACT FROM ACID LEACHING OF DIGESTEK UNDERFLOW

25% excess H_2SO_4, 25°C, 15 mins. extraction time

Component	Concentration		
	gms/litre	mg./gm. dry sludge	% extracted
Fe^{++}	5.30	75.5	100
Al^{+++}	0.540	7.7	98.7
Ca^{++}	0.660	9.6	(*)
Zn^{++}	0.143	2.1	73
Cu^{++}	---	---	0
Mn^{++}	0.021	0.30	91
Cr^{+++}	0.030	0.43	54
P	2.575	36.8	98.4
Organic carbon	3.8	54.3	

(*) Most of the calcium is precipitated as $CaSO_4$

tions they do not go into solution. In the case of the extract from the filter cake, a significant amount of ferric iron is present, and hence it may be possible for copper to exist in the cupric form. The same reasoning may be applicable to the reduced chromium extraction observed from digester underflow solids, with hexavalent chromium being more readily extracted than the trivalent compounds.

4. SEPARATION OF METALS AND PHOSPHATES FROM EXTRACTS BY CHEMICAL MEANS

4.1 General

From observation and the colours of the extracts obtained both from the conditioned sludge filter cake, and from the digester underflow it was apparent that a good deal of acid-soluble organic material was present. An additional purification step is probably desirable, primarily to separate the metallic cations and the orthophosphate from the water soluble organic material.

Since the metals all form insoluble phosphates and insoluble hydroxides in neutral or alkaline solution, this presented a simple technique of separation. Solubility product data for the possible hydroxides and orthophosphates that would be formed can only be used as an approximate guide, inasmuch as the exact nature of solid precipitates formed with phosphate at various pH values is not definitely known for many of these cations. In addition to solubility product data and data on stability constants, some experimental work has been reported in the literature, notably that of Recht and Ghassemi (1970) on aluminum and ferric phosphates, and Ghassemi and Recht (1971) and Singer (1972) on ferrous phosphates. Most of the experimental work has been carried out in very dilute solutions, typical of concentrations found in wastewater treatment plants. In the extracts prepared here, the solutions are only moderately dilute, and are of the order of more than a hundred times more concentrated than normal wastewaters. Therefore, precipitation reactions can occur nearly completely and rapidly.

Published experimental studies indicate that ferric iron - orthophosphate compounds begin to precipitate at pH values above 2.0 and the optimum range for precipitation is at pH 3.5 - 4.0. Aluminum - orthophos-

phate compounds precipitate initially at a pH of 2.5 - 3.0 and the optimum pH is in a range of 4.0 - 6.0. Ferrous ion appears to precipitate with orthophosphate ion as a stoichiometric ferrous phosphate. Precipitate of this compound appears at a pH of 6.0 and the optimum pH is around a value of 8.0. For all three cations as the pH increases above 9 the orthophosphate becomes solubilized again.

Pascal (1962) has reported that when orthophosphate is added to a zinc salt in solution at a concentration of 0.1 N, that precipitation of a zinc phosphate ($Zn_3(PO_4)_2$) begins at pH 5.6. Similar data on copper, manganese or chromium phosphates may be available, but no exhaustive search for this information was carried out because of the small amounts of these constituents in the extract. Calcium-orthophosphate chemistry is complicated and mixtures of phosphates are usually obtained in precipitates. However, according to Van Wazer (1958), when calcium is added to a solution containing orthophosphate the first solid to appear as pH is increased is monocalcium phosphate, $Ca(H_2PO_4)_2$, at a pH from 4.0 -4.5. As further calcium is added up to one equivalent, pH tends to decrease and mixed phosphates are precipitated, for example, $CaHPO_4$ and hydroxy apatites (sometimes given the formula $Ca_5(OH)(PO_4)_3$).

4.2 Purification by Precipitation of Extract from Filter Cake

A number of liquids from different extractions were combined to give a sufficiently large quantity of extract solution for precipitation tests. The composition of this combined extract, all of which was prepared from the same sample of filter cake as used in previous tests, is given in Table VI.

A sample of the extract was placed in a beaker and pH was measured continuously while sodium hydroxide solution was added until the pH reached a predetermined value. As precipitiation occurred the pH tended to decrease and therefore sodium hydroxide was added continuously with stirring until the pH became constant. This usually accurred in less than 20 minutes and in all cases was complete in under 30 minutes. At the end of this period, when pH had been constant for several minutes, the solution was filtered and a sample of the filtrate was analyzed for various cations or anions. The results of these tests, showing the residual fraction of the cation or anion still remaining in the extract as a function of the pH of the extract,

TABLE VI

COMPOSITION OF COMBINED EXTRACTS FROM ACID EXTRACTION OF FILTER CAKE

Constituent	Initial Concentration (gm./litre)
Iron, ferric	4.16
Ferrous	6.64
Aluminum	1.20
Calcium	1.63
Zinc	0.25
Copper	0.125
Chromium	0.060
Phosphorus	4.50
Total Carbon	6.0
pH	0.7

are shown in Figure 4. In accordance with the approximate predictions from solubility data, the first precipitate to form was the ferric salt, presumably a hydrated phosphate complex. Inasmuch as the mol ratio of ferric/phosphate is less than one, probably not all the phosphate will combine with ferric ion even if the precipitate is a hydrated ferric-phosphate compound (see for example Recht and Ghassemi, 1970). Precipitation of the ferric orthophosphate complex begins at a pH of 1.5 and virtually all the ferric ion has been removed by the time the pH has been increased to 2.5. Precipitation of the aluminum phosphate complexes begins also at about pH 1.5, but from the results shown in Figure 4, it appears that the formation of the ferric complex is favoured slightly and the aluminum complex formation does not proceed rapidly until most of the ferric ion is depleted. Again this is in agreement with previous experimental results obtained by others (Recht and Ghassemi, 1970). By the time the pH has risen to 3 all the ferric ion and most of the aluminum has been precipitated and has removed about 90% of the phosphate in solution.

At pH 3 copper and chromium also begin to precipitate and by the time the pH is equal to 5, essentially all of these materials have been removed from solution. From a pH of 4 to 5 most of the zinc is precipitated but very little ferrous iron has been removed, even at a pH of 5. The behaviour of calcium is interesting. About one-half of the calcium is removed immediately the pH is increased from its original value of 0.7 to 1.5 and then very little additional calcium precipitates as the pH is increased to 5. The first formation of monocalcium phosphate, as discussed earlier, is supposed to take place at a pH above 4, and it would appear that this initial precipitation of calcium at a lower pH is not likely to be in the form of a calcium phosphate. There is a relatively small amount of calcium in solution and an examination of solubility data indicates that as pH is raised, the solubility of calcium sulphate decreases by about 25%. It is likely, therefore, that this initial decrease in calcium content of the filtrate over a pH range of 1.5 - 3.0 is due primarily to a change in solubility of the dissolved calcium sulphate.

An examination of the results suggests that when ferric iron is present in the majority, it would be possible by adjusting the pH of an extract to 3 to remove essentially all the ferric iron, most of the alumium

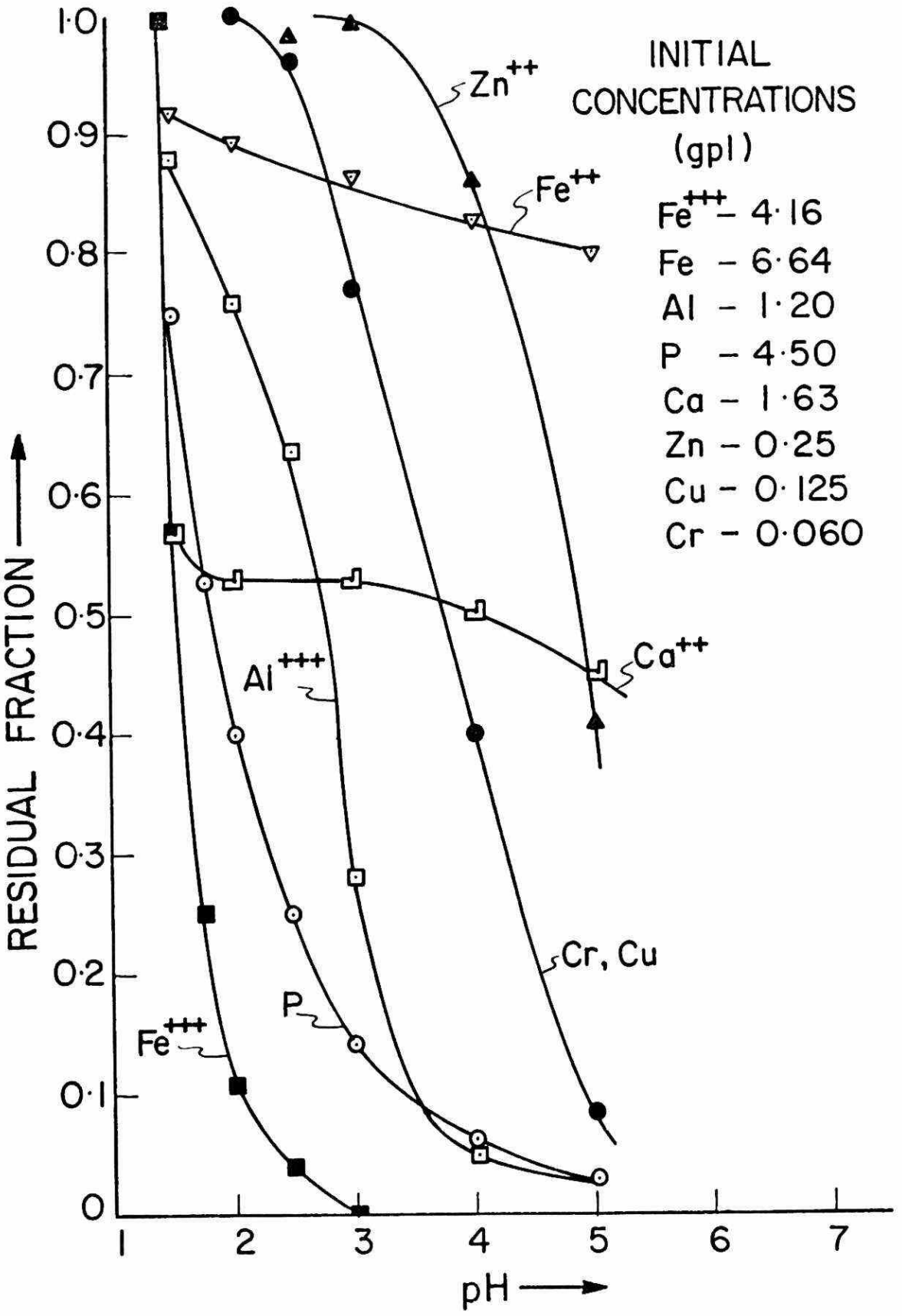

FIGURE 4 Precipitation of Metals and Phosphate from Extract Solution - Conditioned Filter Cake

and all of the orthophosphate, and leave in the solution the bulk of the heavier metals such as copper, chromium, zinc, as well as any ferrous iron. While this approach to a separation is of doubtful value for the present extract because of the bulk of iron is in fact in the ferrous form, it could well be a very useful approach for sludges which have not undergone anaerobic digestion. In these sludges it would be expected that the iron would primarily be in the ferric form. Similarly, it may be that sludges in which alum has been used for phosphate removal, whether they have been anaerobically digested or not, may well be suitable for treatment by this type of selective precipitation.

In this work sodium hydroxide was used in order to adjust the pH of the extract. There is no necessity to use sodium hydroxide, which is a relatively expensive chemical, as the pH adjustment could have been carried out as successfully using lime. However, in this case, a rather more voluminous precipitate would be obtained because additional quantities of calcium sulphate would precipitate, but this would present no particular problem when carrying out a selective precipitation.

The precipitates obtained contained a good deal of metallic hydroxides as well as phosphates, and were fairly flocculent in nature. They did not filter particularly well. While the filter cake containing the heavy metals probably has a significant commercial value per pound, the very small quantity of it would not likely make it worhtwhile to consider it as a commercially useful source of heavy metals.

4.3 Purification by Precipitation of Extracts from Digester Underflow Sludge

The composition of the extract used has already been given in Table V. Because less excess acid was used in this case, the initial pH of this extract was 1.5 as compared to a pH of 0.7 for the extract prepared from the conditioned filter cake solids. The procedure for carrying out the precipitation from these extracts was essentially the same as for the filter cake extracts, and the results obtained are again largely predictable from the known solubility data. These results are shown in Figure 5 for the major cations in the mixture.

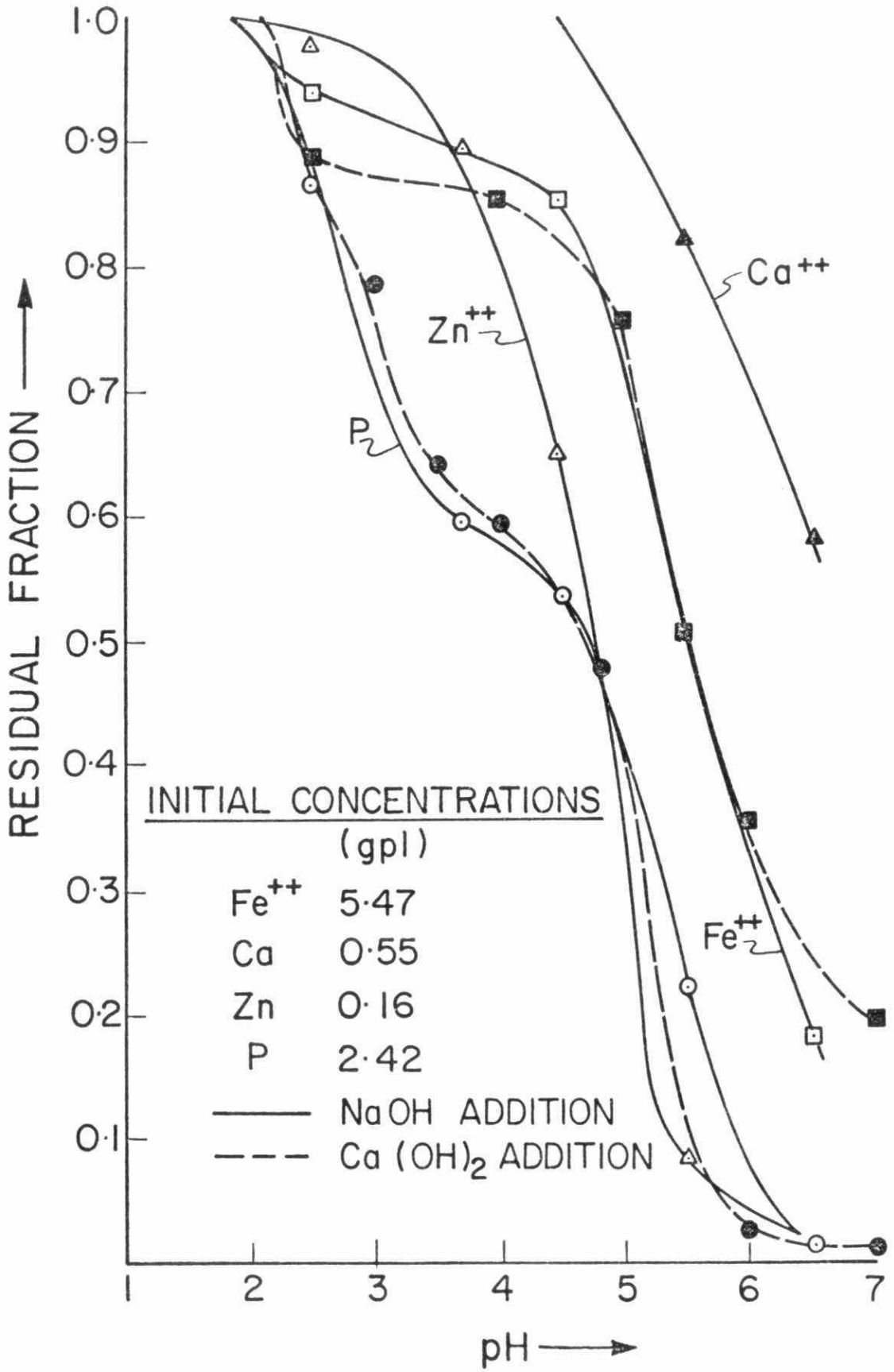

FIGURE 5 Precipitation of Metals and Phosphate from Extract Solution - Unconditioned Sludge Underflow

The principal difference between this extract and the previous one is the complete absence of ferric iron, and the generally lower iron content of the solution. As pointed out earlier, ferrous iron has been reported to combine with orthophosphate to form a fairly well defined ferrous phosphate compound (Ghassemi and Recht, 1971) which does not begin to precipitate until the pH is of the order of 5 or greater. As can be seen in Figure 5 the phosphate removal curve initially drops off between a pH of 2 and 3 due to the precipitation of the alumium phosphate compounds, and somewhat more slowly between pH 3.5 - 4.5, presumably because of the precipitation of the small amount of zinc and minor amounts of other heavy metals.

From the analysis of the leach liquor given, it is apparent that even allowing for the formation of aluminum phosphate and corresponding orthophosphate compounds with other cations, that there is not enough calcium, aluminum, zinc, chromium and manganese combined to remove more than about one-half the total orthophosphate in the solution. In Figure 5 it can be seen that there is an inflection point in the phosphate removal curve at a pH of a little over 4 when about 45% of the phosphate has been removed. Indeed at a pH of 5, one can safely assume that all of the heavy metals, including the zinc, are precipitated either as phosphates or hydroxides and that only a minority of the ferrous iron has yet been removed from the extract. Above a pH of 4.5 the removal rate of orthophosphate parallels the reduction in ferrous ion content of the solution. In the region from 50% to 5% residual phosphate the results correspond to a removal rate of ferrous ion in the molar ratio of 1.5 ferrous to 1 of orthophosphate, as would be required by the formation of ferrous orthophosphate. From the composition of the extract shown in Table V, it can be found that the amount of ferrous ion is just about sufficient to precipitate the remainder of the phosphate in the solution, after the solution has been brought to pH of 4.5. Hence, by the time the pH has been raised to 7, the phosphate has fallen virtually to zero and the ferrous iron is almost completely removed from the solution.

At pH 5.6 a small amount of calcium phosphate compound begins to form and precipitates until essentially all the phosphate has been removed from solution.

The possible application of fractional precipitation is not quite so promising in the case of this extract as for the previous extract. If the pH of the extract were adjusted to 4.5, then the resulting precipitate would contain essentially all the heavy metal ions, a small proportion of the ferrous iron and about one half the phosphate in the solution. It would be possible to dispose of this cake separately after filtering, particularly as the quantity is small. The filtrate would contain the remainder of the orthophosphate, most of the ferrous iron and most of the calcium, as well as the dissolved organic materials and other soluble anions and cations. A precipitate consisting primarily of ferrous phosphate, together with some calcium phosphate, could be obtained by further raising the pH to about 7. Alternately, the entire extract can be brought to a pH of 7 and the resulting solids can be filtered off and then considered as a raw material from which phosphate and ferrous iron might be extracted for possible reuse or recycling. If a sludge under consideration contained relatively large amounts of heavy metal ions, then a selective precipitation might be entirely feasible to dispose of the heavy metals and much of the phosphate as a separate sludge, essentially free of organic matter.

The large sample of the extract was adjusted to a pH of 7, held there until the pH was constant, signifying completion of the precipitation reactions, and the precipitate was then filtered, dried at 100°C and analyzed. The filtrate from this precipitation step was also analyzed in order to check the distribution of the various constituents between the two fractions. The results of analyses on the filtrate and the precipitate are given in Table VII. With the exception of the calcium, all analyses of major components check out with the amount originally present in the extract. From the analysis of the dry cake, it can be seen that the cake is about 70% ferrous phosphate by weight, and contains about 90% of the ferrous iron originally in the extract and about 97% of the phosphorus originally present in the extract. The filtrate from this step is a relatively innocuous material containing only dissolved organics, soluble cations and anions such as sodium, potassium, sulfate, chloride, etc. and only a small amount of

TABLE VII

PRECIPITATION OF METALS FROM EXTRACT FROM DIGESTER UNDERFLOW SOLIDS

Temperature 25°C, Final pH = 7.0

pH adjustment using NaOH

Analysis of Precipitate

Constituent	Concentration		% Recovery	
	mg/gm of dry cake	mg/gm dry sludge	Sludge	Extract
Iron Fe^{+++}	266.0	68.5	91.3	90.7
Aluminum Al^{+++}	25.6	6.6	84.6	85.7
Zinc Zn^{++}	7.8	2.0	69.7	95.2
Calcium Ca^{++}	19.0	4.9	7.6	51.0
Manganese Mn^{++}	0.91	0.23	69.7	76.7
Chromium Cr^{+++}	1.32	0.34	43.0	79.1
Copper Cu^{++}	Nil	Nil	Nil	Nil
Phosphorus P	140	35.9	96.0	97.6
Organic C	3.4	0.8-1		

Analysis of Filtrate

	gms/litre	mg/gm dry sludge	%
Iron Fe^{++}	0.48	6.90	9.2
Zinc Zn^{++}	0.001	0.03	1.1
Manganese Mn^{++}	.004	0.11	33.3
Cr^{+++}, Cu^{++}, Al^{+++}	0	0	Nil
Phosphorus	0.006	0.17	0.5

ferrous ion or phosphate and practically no heavy metals. This material then could be returned to the effluent streams of a treatment plant with no problem.

In preparing the cake having the analyses given in Table VII, sodium hydroxide was used for convenience in adjusting the pH to a value of 7. However, lime could also be used. Further precipitation tests were therefore carried out using the same procedure already described, but with pH adjustment done by addition of 0.04 N $Ca(OH)_2$ to the extract whose analyses is given in Table V. The variation of the concentrations of ferrous iron and phosphate as pH was increased are shown as dashed lines in Figure 5. It is apparent from the similarity of the results that the nature of the metallic precipitates are virtually the same regardless of whetehr NaOH or $Ca(OH)_2$ is added.

In the results shown in Table VII, the iron is reported as ferric iron. When this cake is filtered at a pH of 7 and the organic materials are removed after washing the cake, oxidation of the ferrous material occurs very rapidly in the air and the precipitate rapidly assumes the normal brownish ferric colour.

4.4 Oxidation of Ferrous to Ferric Iron in Sludge and Extract Solutions

It is apparent from the precipitation results given in Figure 5 that the removal and separation of phosphate and metal ions is simplified if the iron is present either entirely in the ferric form or entirely in the ferrous form. In the case of the conditioned sludge filter cake, there were roughly equal amounts of ferrous and ferric iron present. An attempt was made to oxidize the filter cake before acid extraction in order to convert all the iron to the ferric form. This was done by slurrying a sample of the conditioned filter cake, adjusting the pH to between 9 and 10 and then heating it to 170°F and aerating it for one hour. No measurable oxidation was found to occur in this period. A similar test was done using a sample "as taken" of the unconditioned digester underflow, which had a pH of 9.1. This sample was also held at 170°F for one hour while being vigorously aerated and again no measurable oxidation of ferrous to ferric iron occurred. These results are in agreement with results reported by Singer and Theis (1972) who

suggested that times of three hours or more were needed to order to oxidize a reasonable proportion of the ferrous iron to ferric iron in the presence of organic compounds. On the other hand, a sample of the filter cake consisting largely of ferrous phosphate, which was prepared from the extract from the underflow solids, was reslurried and adjusted to a pH of 10.7. It was then aerated at room temperature and in less than 15 minutes, all the ferrous iron had been converted to the ferric form. Again this result is in agreement with the work of Singer (1970) and others, as reported by Singer, who pointed out that in the absence of organic compounds, the oxidation of ferrous iron proceeds very rapidly when the pH is greater than 7.

5 SUMMARY

When phosphate removal is practised in a treatment plant, nearly all the metals and phosphate regardless of source appear in the final sludge. Concentrations may be high enough to affect the use or disposal method of the sludge.

Metals and phosphates can be easily removed from anaerobically produced sludges by extraction with dilute acid. Either thickener underflow or dewatered filter cake are satisfactory sludge sources. Some variations in degree of extraction will occur if metals e.g. iron or copper, can be in more than one valence state, and depending to the acid used for extraction.

The extract solution after filtering can be fractionated by selective precipitation over the pH range of 2.5 - 7.5 into solids each containing a majority of some of the metallic cations. These products are mixed phosphate and hydroxides of the metals. The residual liquor contains most of the water soluble organics and is free of most metallic cations and of phosphates.

The crude metal-phosphate solids products can be further treated by conventional means to recovery phosphate or specific metallic components. Based on amounts in the influent streams or added as treating chemicals, these crude solids will contain 80-90% of the iron, aluminium, zinc and phosphate. The fractional recovery of other heavy metals depends on the nature of the original sludge.

ACKNOWLEDGEMENT

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SLUDGE HANDLING AND DISPOSAL PRACTICES IN THE REGIONAL MUNICIPALITY OF NIAGARA

by

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Regional Municipality of Niagara

INTRODUCTION

The Regional Municipality of Niagara was established on January 1st, 1970, by an act of the provincial government. It is comprised of 719 square miles, and has a total population of approximately 350,000 persons. The Region has a large amount of rural and agricultural land, but about 70% of the population is concentrated in the three largest centres, St. Catharines, Niagara Falls and Welland. The fruits and grape crops from the Region are well known; there is a strong industrial base, and tourism is an important factor in the economy of the Region.

There are currently a total of twelve sludge producing plants in the Region. Except for Grimsby, Chippawa and Crystal Beach, all sludge is anaerobically digested. The Crystal Beach plant employs aerobic digestion; the Grimsby and Chippawa situations are discussed later.

The sludge sources are the Grimsby and Grimsby Beach plants in Grimsby, the Beamsville plant in Lincoln, the Port Dalhousie and Port Weller plants in St. Catharines, the Niagara Falls and Chippawa plants in Niagara Falls, the Niagara River and Crystal Beach plants in Fort Erie, the Port Colborne East and West plants in Port Colborne, and the Welland Pollution Control Plant.

The overloaded and outmoded Grimsby plants and the Beamsville plant are to be replaced in 1976 by a single centrally located four MGD plant currently under design.

The Chippawa plant is to be taken out of service when the South side sewer scheme is completed this fall. Flows from the Chippawa area will then be treated at the larger Niagara Falls plant.

Studies are also under way to consolidate treatment of Port Colborne's wastes at a single plant. This will be at the site of the existing West Side plant or at an entirely new site to the north of town in an industrial park.

When these various works are completed, there will be eight sludge producing plants in the Region. The projected sludge volumes for 1974 are shown on Table 1. Estimates have been made by consultants of future sludge volumes, The 1980 and 1990 sludge predictions are shown on Table 2. Increases in volume can be attributed to: 1) increased flows, 2) expansion to secondary treatment, 3) phosphorus removal.

Current Disposal Practices

The digester at the Grimsby plant has been inoperative for many years. No efforts have been made recently to place it into operation, as the new plant was originally scheduled to be in service by this time. The digester serves only as a holding tank for raw sludge. Until recently, this raw sludge was disposed of in remote areas on farm land where it was immediately ploughed under. This was carried on with the approval of the Ministry of the Environment. During wet periods, the sludge was trucked to either Welland or the Niagara Falls plant where it was digested with the sludge generated at these plants. Sludge volume was small enough that these methods could be utilized without any problems recurring. However, to prevent any reaction associated with this sludge from affecting disposal of properly digested sludges, the Grimsby sludge now is all treated at one of the larger plants.

Digested sludges from the Grimsby Beach, Beamsville, Port Dalhousie and Port Weller plants are disposed of under a single contract. Land disposal is the method employed for the digested sludge, but as a result of difficult soil conditions (a heavy clay), storage is required for several months of the year. Difficulties in meeting requirements set down by the Ministry of the Environment and the Environmental Hearing Board resulted in the contractor closing down his major storage site in the summer of 1974 and application will probably

TABLE 1

Gallons of Liquid Processed Organic Wastes

Sewage Treatment Plant	1974
Grimsby	288,000
Beamsville	44,000
Port Weller	5,817,000
Port Dalhousie	2,597,000
Niagara Falls	2,448,000
Fort Erie	144,000
Crystal Beach	40,000
Port Colborne	894,000
Welland	800,000
Total	13,072,000

TABLE 2

Gallons of Liquid Processed Organic Wastes

Sewage Treatment Plant	1980	1990
Grimsby	5,400,000	6,900,000
Beamsville Port Weller Port Dalhousie	19,770,000	24,525,000
Niagara Falls	11,400,000	14,250,000
Fort Erie Crystal Beach	4,155,000	4,995,000
Port Colborne	3,210,000	4,425,000
Welland	7,965,000	9,720,000
Totals	51,900,000	64,815,000

have to made to the Ministry of the Environment for an emergency permit for sludge storage during the wet fall and winter months this year. We have in fact already constructed sludge storage lagoons for this purpose. The double handling of sludge from the storage has also led to additional expense which will have to be borne ultimately by the municipality.

Experimental storage sites have been set up on individual farms. These lagoons were sized to meet the expected requirement of sludge for each farm. This scheme had the advantage of making the sludge available to the farmer when it would best benefit the particular crop being grown. These however, have not been approved by the Ministry of the Environment for full-scale use, and it appears that adverse public outcry will preclude the long term use of this method.

The Niagara Falls plant is fortunate in being located on a site adequate for future expansion and well separated from odour sensitive areas. Drying lagoons have been estabished on the plant site These lagoons provide a full year's storage. Supernatnat from the lagoon is pumped back to the head of the plant. This decanting process, natural drying, and the freezing action in the winter reduces the water content in the sludge from about 90% to 75 or 80%. This material is removed from the lagoon by dragline and dump truck and is windrowed immediately adjacent to the drying lagoons, where it is allowed to dry for another year reducing the water content to about 25%. This material is offered to the public and then removed by landscapers who use it as a supplement to their top soil.

This method of disposal is inexpensive and results in re-use of the beneficial qualities of the sludge. Unfortunately the area available for lagooning is reduced by proposed plant expansions. The small volume of raw sludge from the Chippawa plant is trucked to the Niagara Falls plant for treatment.

The Town of Fort Erie has provided space at its landfill site for the disposal of sludge from the Niagara River plant, which serves the old Town of Fort Erie. The aerobically digested sludge from Crystal Beach is also disposed of at the municipality's landfill site. Since the

implementation of phosphorus removal in December of 1973, more sludge has resulted and additional space will likely have to be made available. (Phosphorus removal is not required at the remaining plants until the end of 1975.)

The sludge from both of the Port Colborne plants are disposed of at this municipality's landfill site.

Prior to the expansion to secondary treatment at Welland, on-site lagoons provided storage when land spreading could not take place. With the installation of the secondary facilities, a new site will be required and negotiations have begun with the St. Lawrence Seaway Authority to use some of their surplus lands from the canal relocation. Investigations into pumping the sludge about 4,000 feet to the proposed site has been undertaken by a consultant. It is proposed that supernatant be returned to the plant, and a drying operation similar to Niagara Falls be initiated.

Research Projects

The Region has been involved in two research projects dealing with the disposal of sludge. The first of these is titled "The Land Application of Sludge Under Adverse Conditions." Tests were carried out using various common types of vehicles employing different traction modes to determine whether a suitable method existed to spread sludge on fields made impassable by rain and/or thawing conditions. Vehicles tested included tank trucks, front-end loaders, bulldozers, all-terrain vehicles and sludge injectors. Also investigated was a spraying system utilized by a contractor on a trial basis. The best approach appeared to be pumping through irrigation piping and spraying, but problems were encountered with plugging, freezing and windspray. The particular equipment used by the contractor was sold under the trade name "White Rain". An adaptation of an altering vehicle appeared to be the second best approach. These studies were based on the acceptance of land spreading as a viable disposal method.

The second research project is through the provision of data as a test case for "A Computer Aided Technique for the Design of

Regional Sludge Disposal Systems". This program was developed by B & P Silveston, Engineers, and employed computer selection to optimize use of various disposal alternatives. This project is still under way and should lead to economic long-term solutions if the proper information is provided for computation.

There is a strong feeling among members of the Region's Public Works and Utilities Committee that the disposal of sludge would best be handled under the direction of regional staff rather than left to the direction of a contractor. Preliminary investigations into the acquisition of a site suitable for this purpose have been undertaken. There is also the possibility that this site could be used for the disposal of solid wastes should legislation be changed.

If such a system is selected, consideration has been given to the handling of sludge in tank trailers owned by the Region. These would be hauled under contract on a rotation basis. This method will allow the tanks to be filled when convenient for operating staff, would not tie up a truck driver during loading times and would allow closer control of the disposal operation.

This alternative along with many others, such as vacuum filtration, centrifugation, and a central incineration site, are being investigated under the "computer aided" research program. Hopefully results will be known to allow for budgetting in 1975.

CONCLUSIONS

1. The volume of sludge requiring disposal is increasing rapidly within the next few years, but the rate of increase will probably decline somewhat after 1980.
2. Costs are also increasing:
   In 1974, sludge disposal accounted for 8.8% of the operating budget. The average cost was 1.2¢ per gallon, and the total cost of sludge disposal about $150,000.
   In 1976, we expect sludge disposal to account for 12% of the total operating budget. By 1980, if the current unit costs are not increased, the annual cost of sludge disposal may well be in excess of one-half million dollars.

3. A long term dependable solution is required if the treatment plants are to function as designed. Irregular sludge hauling creates a heavy digester supernatant which must be treated in the plant and leads to organic overloading, and subsequent deterioration of plant effluent. A back-up system to vulnerable disposal methods is also essential.
4. Future government regulations may have serious effects on sludge disposal programs, particularly costs in the Niagara region and for many other municipalities. It is suggested that the Ministry of the Environment review the effect of any new regulations in terms of cost of operation. It is also suggested that if major changes in regulation occur, that advance notice adequate to investigate and initiate alternatives be given. Some thought might also be given to subsidies for this type of program.
5. The disposal of sludges on farm lands can be a benefit. This has been well documented. Current research should continue to identify unknowns and potential problems, but should also provide practicable solutions. When new regulations are such that they inhibit established practices, regulatory agencies should be aware of the costs of alternatives.

SLUDGE HANDLING AND DISPOSAL PRACTICES IN METROPOLITAN TORONTO

by

W.A. Salib

The successful disposal of the solids extracted from wastewater by the various processes employed, is a most important link in the treatment chain and is one which can affect most other process steps in a very serious way, if it fails or falls behind the daily sludge production.

Since Metropolitan Toronto's formation on 1st January 1954, it has been a continuing challenge to find satisfactory and economical sludge disposal systems for the plants under its jurisdiction.

When Metro Toronto was created, there were 17 treatment plants in operation in the City of Toronto and the suburban municipalities, and two further plants under construction. The oldest and largest was the Main Plant (Ashbridge's Bay) built in 1912.

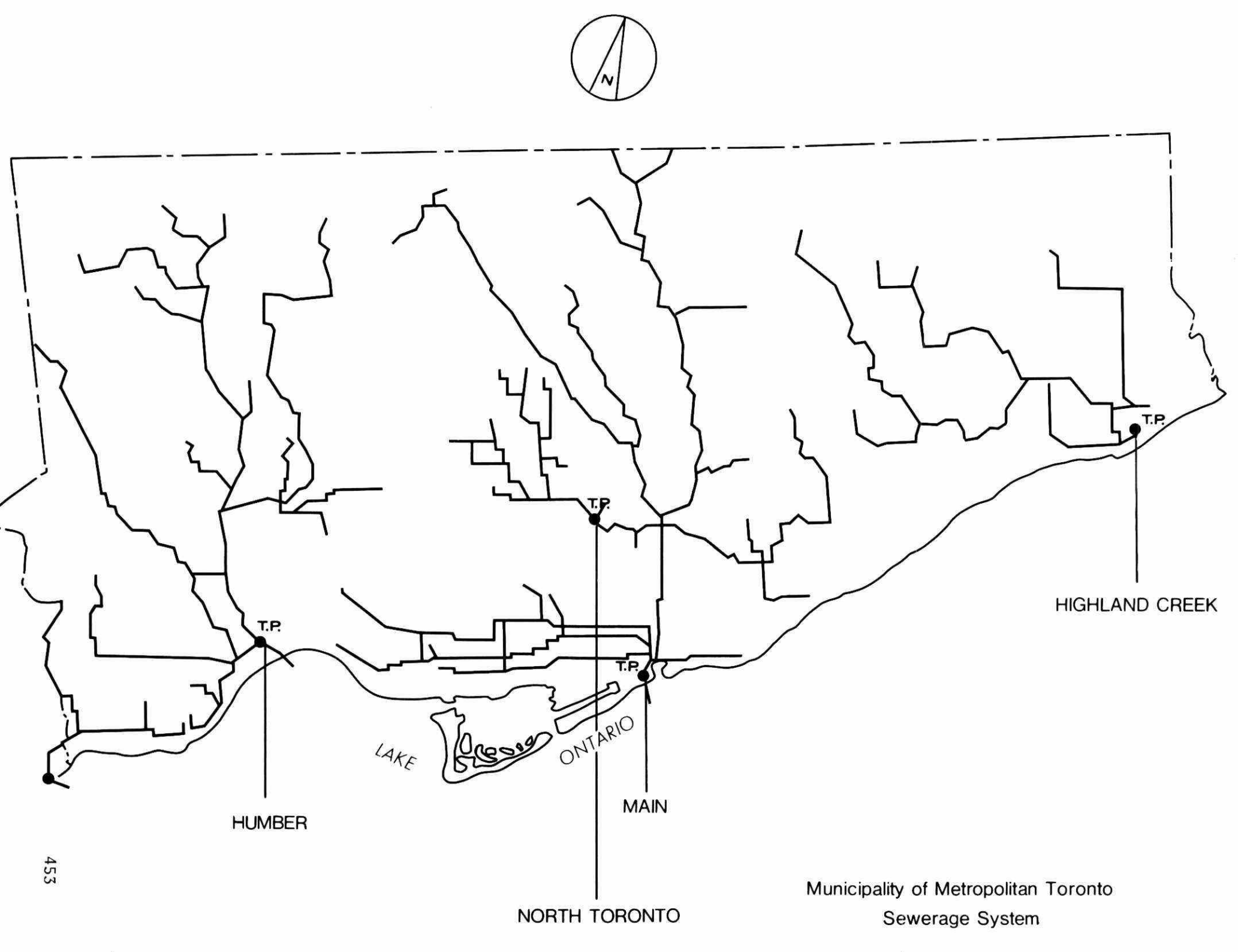
The sludge disposal systems employed at the 19 plants consisted in handling the sludge in either the "raw" or "digested" forms:

a) Handling of Sludge in the Raw Form

- Haulage of liquid sludge from holding tanks to farm land.
- Conditioning with ferric chloride of the raw sludge (mixed waste activated and primary) followed by vacuum filtration and haulage of the filter cake to farm land.

b) Handling of Sludge in the Digested Form

- Pumping to sludge lagoons.
- Haulage to farm land.
- Drying on sand beds with the dried sludge either taken by interested local citizens or the surplus hauled to land disposal.
- Conditioning with ferric chloride and lime followed by vacuum filtration and haulage of the filter cake to land disposal.
- Elutriation, conditioning with ferric chloride and lime followed by vacuum filtration and incineration or heat drying.



Municipality of Metropolitan Toronto
Sewerage System

DISPOSAL SITES

In 1954, farm lands were still under cultivation in much of the northern portions of the present Boroughs of Etobicoke, North York and Scarborough and thus the distances the sludge had to be trucked for disposal were relatively short. However, with the formation of the Metro system of government, one of the benefits derived was the provision of more serviced building lots when construction of the Metro trunk sewer system got underway. At the same time, some additional temporary waste water treatment facilities were premitted for short periods which enabled a farily rapid housing and industrial development of the area to take place. This, of course, caused the agricultural land within Metro's boundaries to be bought up by land developers and taken out of agricultural use with the result that disposal sites became more distant from the treatment plants.

When disposal sites were required in municipalities outside Metropolitan Toronto's boundaries, permission for land disposal had to be obtained from the Medical Officers of Health. In some jurisdictions, permission was refused, in others, it was permitted under certain rules all of which did coincide with our practice. Some of the regulations were that liquid sludge could not be spread on fields closer than 100 feet from a road or 200 feet from a watercourse. The objective was to prevent nuisance complaints from the passing public and to prevent run off into watercouses.

As the availability of disposal sites became more critical, incineration had be considered more carefully as a practical mean of disposing of sludge.

METRO'S SEWERAGE SYSTEM

The plan for Metro's sewerage system, which was put into effect early in 1954, was designed to provide trunk sewers which would convey the waste water to three major plants on Lake Ontario and one smaller plant on the Don River.

1) Highland Creek Treatment Plant in the easterly section, serving the Highland Creek watershed.

2) Main Treatment Plant (at Ashbridge's Bay) serving the central area through which the Don River and its branches flow.

3) Humber Treatment Plant to serve the westerly portion of Metro in the Humber River watershed.

4) North Toronto Treatment Plant, on the Don River.

When the Humber Treatment Plant was put into operation in 1960, with the trunk sewers extending northerly from it and the Main Plant, all the small plants on the Humber and Don Rivers were taken out of service gradually.

Systems Presently Used in Sludge Handling and Disposal

By the 1960's, the sludge disposal picture had been consolidated to the four treatment plants envisaged in the 1954 engineering report on the trunk sewer system and treatment plants required to serve the Metropolitan Toronto area, and the sludge disposal systems were as follows:

1) Highland Creek Treatment Plant (16 mgd capacity)
Heated anaerobic digesters with digested sludge pumped to lagoons from which it was periodically removed in a cake dried form to an area where private citizens could obtain it as a soil conditioner for lawns, shrubs and flowers.

The low cost lagooning had to be abandoned recently by reason of the encroachment of private housing units into the area immediately to the north-east and north-west of the plant. As housing moved closer to the plant, complaints of odours from the lagoons became common. The odour was a musty, earthy odour which was aggravated by reason of the proximity of the plant to Lake Ontario which in turn was instrumental in causing an onshore current of cool air to rise over the warmer air of the Highland Creek Valley most evenings. Thus the moist musty air rising from the treatment plant lagoons was trapped for several hours each evening and spread up the valley. This gave rise to numerous complaints.

SYSTEMS PRESENTLY USED IN

SLUDGE HANDLING AND DISPOSAL

TREATMENT PLANTS	CAPACITY IN M G D	SLUDGE PROCESSING				SLUDGE DISPOSAL
HIGHLAND CREEK (1956)	16	Anaerobic Digestion	-	Polymer	Centrifuges (Solids Bowl)	Haulage to landfill area
MAIN (1912)	180	Anaerobic Digestion	-	Polymer Filters	Vacuum Filters	Incineration
HUMBER (1960)	62	Anaerobic Digestion	Elutriation	$FeCl_3$ + Lime	Vacuum Filters	Haulage to Landfill area
NORTH TORONTO (1927)	10	Anaerobic Digestion	Elutriation	$FeCl_3$ + Lime	Vacuum	Air drying storage, on land removal by interested citizens

To provide, as quickly as possible, a dewatering device which would allow us to abandon the lagoons, we turned to a solid bowl centrifuge. In 1970, a centrifuge came into operation using a polymer as the conditioning chemical to produce a good solids capture and a reasonably clear centrate. The original machine was supplemented by a second machine in 1972 and a further two are on order with delivery scheduled for late this year.

The centrifuge cake produced by the operation is pumped with a progressive cavity pump to Metro owned dump trailer for disposal at a landfill site. The cake solids vary between 17 and 20 percent dry sludge solids.

2) Main Treatment Plant (180 mgd capacity) Heated anaerobic digesters with the digested sludge being pumped to elutriation tanks prior to conditioning with ferric chloride and lime followed by vacuum filtration. The sludge cake was then incinerated or heat dried to a dry sludge which was sold to a commercial operator who bagged some of it as a soil conditioner and sold the rest in bulk to such enterprises as golf courses and tobacco farms.

In 1964, the use of ferric chloride and lime was superceded by the use of a polymer. This new conditioner produced a sludge cake of essentially the same sludge solids content (15 to 17 percent dry sludge solids) and with no additional non volatile material to be handled as ash from the incineration operation. It also eliminated the elutriation process and the troublesome lime encrustation caused by deposition of calcium carbonate on filtrate pumps and lines, incinerator parts, ash pumps and ash lines. The chemical cost of the polymer was somewhat greater than that of ferric chloride and lime, but this was offset by the previously noted elimination of the elutriation process

and the maintenance resulting from the lime encrustation, in addition to the increased tonnage of sludge solids which could be handled by the incinerators.

In 1970, the heat drying of sludge ceased due to the inability of the commercial operator to market more than approximately two percent of the plant output. In addition, the off gas scrubbing system must be revamped to meet today's more restrictive air pollution requirements.

3) Humber Treatment Plant (62 mgd capacity) Heated anaerobic digesters, digested sludge elutriation followed by vacuum filtration using ferric chloride and lime as conditioning chemicals and disposal of the filter cake at landfill sites as a top dressing for eventual grass growing.

4) North Toronto Treatment Plant (10 mgd capacity) Heated anaerobic digester followed by elutriation, vacuum filtration, cake storgae with air drying followed by rotovation on land for further sun drying and finally disposal by removal from the site by interested citizens who used it as a soil conditioner for lawns and flowers.

Conditioning of Sludge Prior to Vacuum Filtration

Conditioning of sludge to prepare it for vacuum filtration is based mainly on the two physico-chemical reactions of:

a) Coagulation by neutralizing the electric charge. The sludge being normally anionic (-) requires a cationic (+) chemical.

b) Flocculation by the addition of lime or a viscous chemical to give the coagulated sludge enough body to resist the sucking effect of the vacuum filter.

Different chemicals were tried in Metro's plants; the following were found to be effective.

1) Ferric Chloride and Lime proved to be quite successful. The solids content of the filter cake vary between 20 and 22 percent, of which, 15 to 17 percent are sludge solids.

The digested sludge being normally alkaline, the elutriation process was recommended prior to conditioning with ferric chloride to reduce the ferric chloride consumption.

The maintenance problem associated with the use of lime is severe, because of the lime encrustation caused by the deposition of calcium carbonate on the walls of mechanical equipment.

2) Waste Steel Pickle Liquor and Lime At a certain time, a source of waste steel pickling liquor was available in Metro. Waste steel pickle liquor (ferrous sulphate or ferrous chloride) and lime were used as conditioning chemicals prior to vacuum filtration at the Humber & North Toronto Treatment Plants.

This had the advantage of low cost in that it was available for the cost of hauling it by tank truck from the manufacturing plant to the treatment plants.

The disadvantages were:

- the concentration of iron in the form of ferrous sulphate was not closely controlled.
- there was a small residual free acid content.
- the ferrous salt is not as effective a coagulant as the ferric salts.

As both the above mentioned plants had a generous installed capacity, the reduction in filter yield did not adversely affect the plants capability of meeting their quota of sludge to be filtered and thus the lower cost per ton of dry solids filtered was a very attractive incentive to use this waste product until 1972 when the company changed its steel pickling process to a regenerative system and thus did not have the previous waste product available.

3) Polymers vary considerably, and their effectiveness for coagulation and flocculation of sludge should be evaluated carefully.

The orginal polymer contracts were on a "performance" basis. That is, the polymer supplier was paid on a tendered price per ton of dry solids filtered. In recent years, the polymer has been purchased on a unit price basis.

Over the period of time that polymers have been used both liquid and granular (powder) polymers have been employed. Each form of the material has its advantages and disadvantages which may be summarized as follows:

	Liquid	Granular
Transportation	Less active ingredient can be transported in equal sized vehicles	Many times as much active polymer can be transported in equivalent volume of vehicle. However, because of its high affinity for water, it should be handled in hermetically closed containers not exceeding 50 lbs. each.
Storage Space	Greater Space required for storage tanks	Much more material can be stored in the space that would otherwise be occupied by liquid storage tanks. The storage space should be dry.
Storage Life	Shorter than as a dry powder	Longer than liquid
Handling	Can be all enclosed and provided with an automatic dilution, mixing and feed system	Requires physical handling to transmit the powder to a soluton. With high electric charge and/or moisture in the air, some difficulties might be encountered. After putting it into solution it is handled as for the liquid.

	Liquid	Granular
Consistency	Different tank loads have different viscosities which leads to "Layering" in storage tanks. This makes a consistent blend quite difficult	Repeated solutions of the same strength with little variation in viscosity can be readily acheived.
Housekeeping	As a closed system, there is little "mess" resulting from the use	Some spillages in transfer from original shipping container are difficult to avoid and this results in a hazardous, slippery condition.

Incineration of Filter Cake

In a plant having waste activated sludge treatment and anaerobic digestion of sludge, the following dry sludge solids figures may be expected:

Unit Weight	
100	Received in the plant
60	Filter cake to be incinerated
30	Ash to be hauled to landfill areas

The experience gained in the operation of multi-hearth incinerators, at the Main Treatment Plant, led us to the conclusion that Incineration is an effective method for complete combustion of combustible matters in sewage sludge; leaving inert ash of a lesser volume and weight.

For a successful incineration operation, certain parameters are to be adhered to and the combustion in the hearths carefully controlled The following are some features to be considered:

1) The maximum hearth temperature be held below the fusion point of ash.
2) The flame temperature of supplementary heat burners be held below the fusion point of fly ash.
3) Supplementary hearth heat be provided by as many burners as is practical, equally spaced around the shell of the furnace, to avoid heat concentrations and reduce thermal stresses.

4) The burner flame should not impinge on the rabble arms, rabble teeth, floor or ceiling of the hearth. This fixes a minimum hearth height.

5) Detention time in the drying zone be adjusted to reduce considerably the moisture content of the cake before exposure to the incinerating temperature.

6) Entry of air to supply sufficient oxygen on all burning hearths should be automatic through the monitoring of oxygen levels in selected hearths which in turn will activate modulating dampers on an air supply at entry points to the hearths.

7) The sludge feed rate should be as constant as possible without abrupt variations.

8) The use of silica sand in preference to incinerator ash, as a hearth bed, reduces the risk of slagging in the bed.

The economical aspect of incineration of sewage sludge puts the emphasis on the moisture content of the filter cake.

Heating one pound of water from room temperature ($70^{o}F$) to the flue gas temperature of an incinerator ($850^{o}F$) requires 1433 B.Th.U., i.e. one ton of water requires 2,866,000 B.Th.U., which is a considerable amount of heat wasted on water in the incineration process.

In an endeavor to overcome this problem, a process called "Thermal Processing of Sewage Sludge" was developed. In this process, treatment of sludge at a temperature of about $400^{o}F$ under a pressure of approximately 450 lbs. per square inch enables its vacuum filtration to a filter cake containing 30 to 40% solids. In addition, it requires no conditioning chemicals prior to filtration, which renders the whole process economically attractive.

Thermal processing of sewage sludge will be incorporated in some of Metro's plants, in the near future.

FUTURE PLANS FOR SLUDGE DISPOSAL

1) Highland Creek Treatment Plant The sludge disposal complex at this plant is under engineering design for the installation of three thermal treatment units, each with a capacity

FUTURE PLANS

TREATMENT PLANTS	CAPACITY IN M G D			SLUDGE PROCESSING
	PRESENT	NEAR FUTURE	ULTIMATE	
HIGHLAND CREEK	16	32	64	Thermal Processing, Dewatering, Incinerating
MAIN	180	200	300	Thermal Processing, Dewatering, Incinerating
HUMBER	62	90	120	Dewatering (x), Truck hauling to the Main and Incinerating
NORTH TORONTO	10	-	-	(Modernization of Present Facilities)

(x) Different Methods of Dewatering Sludge are under consideration

of 100 gallons per minute. The sludge will be a blend of raw, thickened waste activated and digested sludges. The contract for these three units has now been awarded. In addition, a contract has just been awarded for two 7-hearth incinerators, and a further contract will soon be tendered for the supply of additional solid bowl centrifuges. The resultant ash from this complex will be pumped to one of two lagoons on the site.

2) Main Treatment Plant Additional facilities for this expanding plant include a contract which has been awarded for seven thermal treatment units each with a capacity of 208 gallons per minute. A contract has also been awarded for two additional 12-hearth incinerators bringing the total number of incinerators to 7: 2 x 8-hearth and 5 x 12-hearth.

   In the disign stage are the piping system and buildings to house the thermal treatment units combined with a waste activated sludge thickening system, and an addition to the incinerator building, as well as, a 600-foot stack for all the exhaust gases from all the incinerators. When this equipment is in operation the existing incinerators and exhaust gas scrubbers will be revamped to meet the standards of today. As at Highland Creek Plant the resultant inert ash will be pumped to one of two on site lagoons.

3) Humber Treatment Plant At this time, the consultant engineers for this plant are preparing a report dealing with the future recommendations for sludge disposal. A number of options are being carefully considered. At the time of preparing this paper, the most feasible option seems to be to dewater the sludge by some means, still under pilot plant study, to achieve a sludge cake solids level which will provide autogenous combustion, and that cake will be hauled to the Main Treatment Plant for incineration in the units installed at that plant. The added expense of haulage across the city may be justified by the problems which would

be encountered it incinerating units were provided at the Humber Filtration Site, which is in an area where development of high rise apartment complexes is imminent.

4) North Toronto Treatment Plant No plans are envisaged at this time to change from the existing system. However, modernization of the present facilities might be considered.

SUMMARY

At this time, we believe the most feasible and economical system of sludge disposal, for the sludge generated in the operation of relatively large waste water treatment plants, is accomplished by dewatering the sludges to a solids content of 30 to 40 percent, at which point it will provide an autogenous combustion fuel for large multi-hearth incineration, with the resultant ash settled in lagoons. The eventual disposal of the inert ash can be as landfill or, with additional research, the extraction of valuable chemicals may become an economically viable scheme as the cost and availability of some raw materials become more critical.

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